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AUSTRALIAN SKY & TELESCOPE

THE ESSENTIAL MAGAZINE OF ASTRONOMY

ISSUE 85

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Having arrived at Ceres, NASA's Dawn spacecraft has become the first space explorer to go into orbit around a second Solar System body.

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Astronomy above the clouds

There are ground-based observatories, and there are satellite observatories. Each has its good points and bad points. But nothing compares with SOFIA, a jumbo jet with a telescope pointing out the side (see page 16).

SOFIA's advantage is that it can fly high above most of the bad weather, and in particular above most of the water vapour in the atmosphere. SOFIA's telescope is optimised for infra-red astronomy, and water vapour is the enemy of infra-red – it acts as an absorber of wavelengths.

The other big advantage is that SOFIA's pilots and scientists can devise a flight plan that helps it avoid areas of cloudy weather.

I had the great good fortune of tagging along for a ride aboard SOFIA's predecessor, the Kuiper Airborne Observatory, when it came out to Australia in 1994 to study the impact of fragments of Comet Shoemaker/Levy 9 with Jupiter. Flying out of Melbourne, the converted C-141 military airlifter headed out over Bass Strait — to obtain clear skies certainly, but mostly to avoid other air traffic. The most memorable part of the journey was the pre-flight safety briefing, wherein we were warned to not stray more than a few metres from our oxygen masks… for in the case of a sudden decompression, we would be unconscious before reaching them.

Some scientists are not convinced of the economics of operating airborne observatories — and it is true that they add an extra layer of complexity over ground-based observatories. But compared with satellites — the only other option for full-on infra-red observing – they are far more flexible. If something breaks, you can just land, fix it, and head back out again next time. You can't do that with a satellite.

As for SOFIA, let's hope we see it head down our way one day. Maybe another comet will pop up on a collision course with a planet – but hopefully not Earth.

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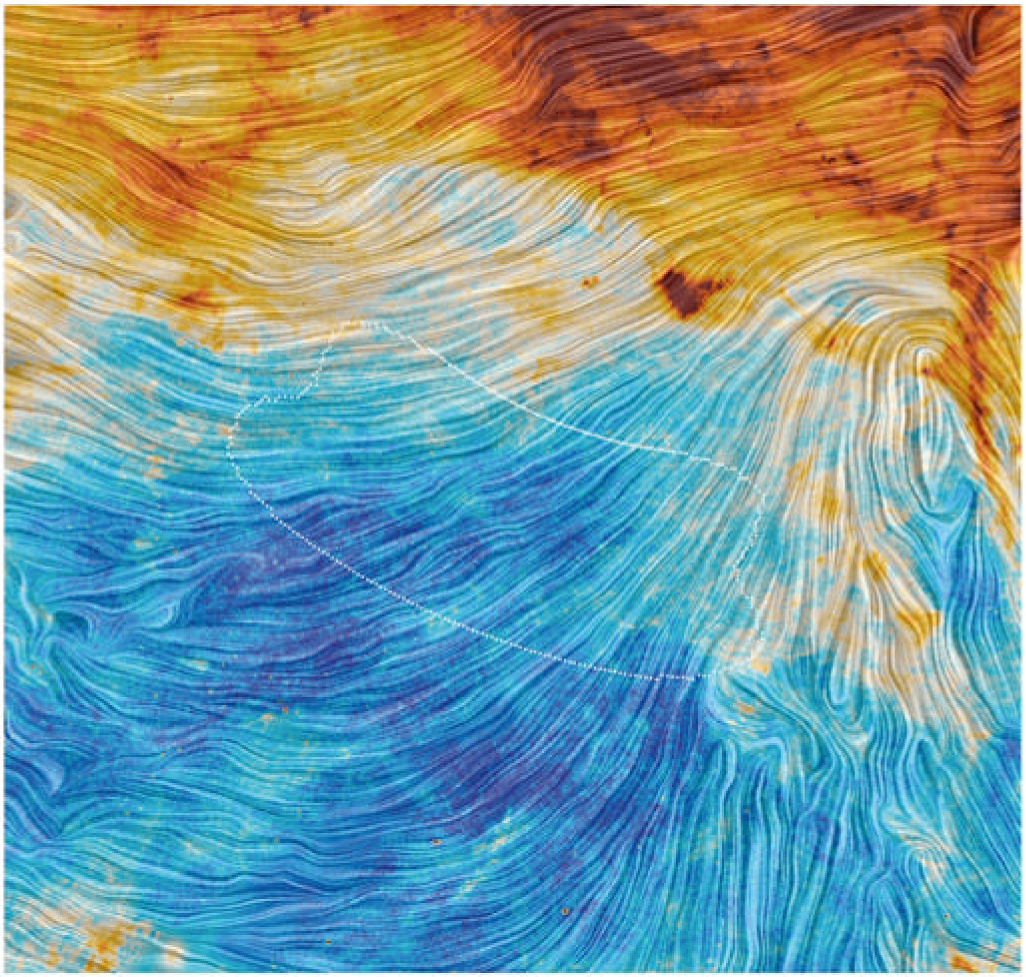
COSMOLOGY I

Inflation signal reduced to dust



This map from ESA's Planck satellite shows the patch of the Southern Hemisphere sky analysed by the BICEP2/Keck projects (white outline, 400 square degrees). Colours represent emission from dust (orange is more, blue less) and lines represent the orientation of the Milky Way's magnetic field. The knot of red to the upper right of the BICEP2 field is the Small Magellanic Cloud. ESA / PLANCK

The long-awaited analysis of swirly polarisation patterns called B-modes affirms that these signals, purportedly from the universe's brief but stupendous spurt of inflationary growth, are probably instead from dust in our galaxy.

Last March, researchers with the BICEP2 and Keck Array experiments at the South Pole reported the detection of B-modes in their cosmic microwave background (CMB) observations. These B-modes, if in fact in the CMB itself, would come from spacetime ripples called gravitational waves that were created by the hypothesised 10 nano-nano-nano-nanoseconds (10^{-35} seconds) of inflationary growth.

Yet skepticism soon replaced euphoria when two other teams using data from the Planck spacecraft suggested the signals might instead be from dust in the Milky Way. Aligned with our galaxy's magnetic field, interstellar dust grains produce polarised emission of the same pattern and angular scale (a couple of degrees) as the primordial B-modes cosmologists are hunting for.

To settle the debate, the BICEP2/Keck and Planck teams combined forces (and data) in a joint analysis. On January 30 the teams announced that the analysis shows that dust in the Milky Way can completely explain the B-modes detected by the South Pole experiments. At most, gravitational waves from inflation could make up only half of the observed signal.

Planck's full data set was crucial in this investigation because it avoids the need to extrapolate. Both BICEP2 and the Keck Array focused on a frequency of 150 GHz, favourable for CMB studies but challenging for dust identification. The Planck satellite, on the other hand, observed nine frequency bands, with seven of those — 30, 44, 70, 100, 143, 217, and 353 GHz — including polarisation measurements. Using those data, astronomers can directly see how dust emission changes from frequency to frequency.

Emission from our galaxy's dust is strongest at 353 GHz (25 times stronger than it is at 150 GHz, in fact). And because Planck reveals the relationship between emission strengths at different frequencies, the researchers could use Planck's exquisite 353-GHz dust map to analyse the detected B-modes. They carefully compared, combined and cross-analysed the observations in order to calculate the implied ratio of how big the spacetime ripples were compared with the ordinary density fluctuations in the material filling space, a ratio called r. Basically, r measures the strength of the gravitational waves and how energetic inflation was. A higher r means more energy behind inflation.

The teams calculated an upper limit of $r < 0.12$, which agrees with the upper limit of $r < 0.11$ from Planck's 2013 results (those included only the first 15.5 months of satellite data). These upper limits favour simpler forms of inflation. Paired with Planck's full data, the limit shows cosmologists should focus on "slow-roll" inflation models, in which the potential energy that drives inflation decreases slowly, like a ball rolling down a gentle hill. A lower energy scale would also be friendlier to string theories, which seek to unite quantum mechanics and gravity.

■ CAMILLE M. CARLISLE

EXOPLANETS I Spin-up to habitability? . . .

Artist's impression of a planet circling a red dwarf star. NASA / ESA / G. BACON (STSCI)

Exoplanets tightly circling their stars might have a better chance of being habitable than previously thought.

Red dwarfs are the most abundant type of star in the Galaxy. They're also roughly one-quarter the Sun's mass, bringing their habitable zones closer in and making it easier to spot Goldilocks planets. But a planet that orbits close enough to a red dwarf to be in the star's habitable zone could become tidally locked, with one face always turned toward the star. Having a perpetual night side could in turn destabilise chemical exchanges between the atmosphere and surface or even cause the atmosphere to collapse.

New research, however, suggests that the effect of the planet's atmosphere might be strong enough to break any tidal locking, allowing the planet to rotate freely.

Jérémy Leconte (University of Toronto and Pierre Simon Laplace Institute, France) and colleagues created a 3D climate model to predict the effect of a planet's atmosphere on the speed of its rotation. It all depends on the amount of starlight able to penetrate the planet's atmosphere and reach its surface. Temperature differences at the surface drive winds. Those winds constantly push against the planet by running into mountains or creating waves on the ocean. Such friction then influences the rotation rate of the planet, helping to speed it up or slow it down.

Astronomers have long seen this effect on the planet Venus, where the atmosphere's influence is so powerful that it forces the planet into a slow retrograde rotation. But planetary scientists didn't think thinner atmospheres like Earth's could throw their weight around as effectively.

Leconte's simulations show that thinner atmospheres actually have a larger rotational effect on their planets. With less scattered sunlight, extra heat reaches the deepest atmospheric layer and creates stronger winds. If Venus had an atmosphere like Earth's, it would spin 10 times faster, the team reports January 15 in *Science*. This is radically different from previous research, which suggested that it would spin 50 times slower. An unlocked planet should therefore have strong atmospheric mixing and stable temperatures.

Although a large number of known terrestrial exoplanets should thus have a day-night cycle, the duration of their days could last between a few weeks and a few months. So these planets would still be far from Earth-like, with only a few days per year, cautions René Heller (McMaster University, Canada).

■ SHANNON HALL

BLACK HOLES I Binary en route to merger?

When galaxies merge, astronomers expect the supermassive black holes lurking in the galaxies' cores to form their own dancing duos, inspiraling and finally coalescing. Yet black hole binaries have proven difficult to find, and astronomers only have circumstantial evidence for them.

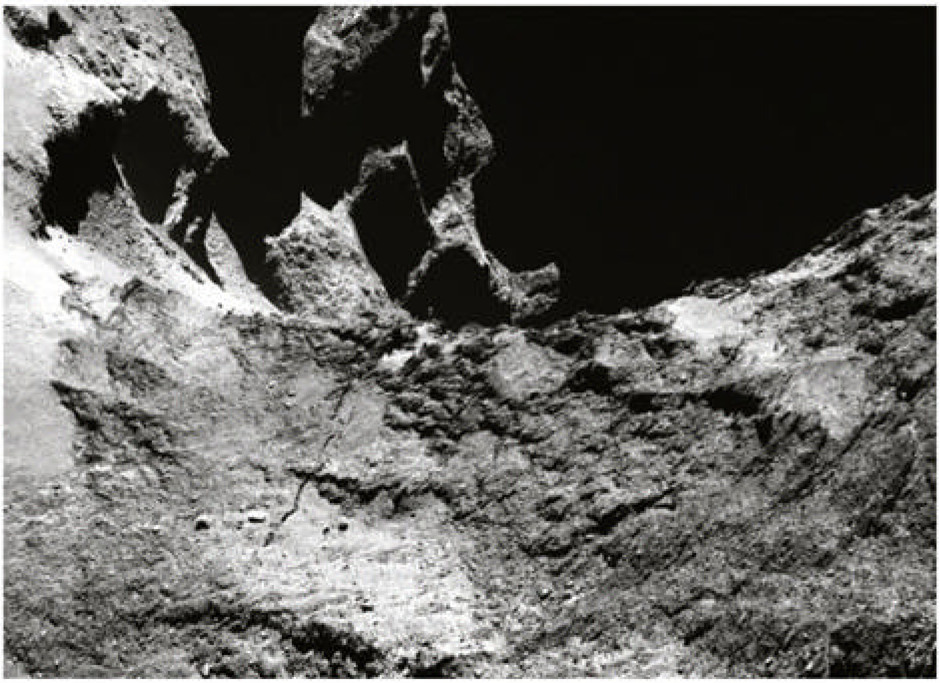
Now astronomers have found the closest-hugging black hole binary candidate yet, Matthew Graham (Caltech) and colleagues announced January 7 in *Nature*.

The team's source, PG 1302–102, is a 'vanilla' quasar that mysteriously pulsates with a period of about five years. Quasars are notoriously variable at emitting radiation at all wavelengths, but randomly so — usually there's no regularity to the changes in brightness. Yet when on a whim the team ran algorithms to check a sample of 247,000 quasars for regular pulsations in brightness, 20 sources popped up, including PG 1302–102, which is the "best-looking" of the bunch. That discovery rate (20 out of 247,000) is close to what's expected by theorists for binaries separated by less than a tenth of a light-year, as this one seems to be.

The distance between the two black holes depends on what their masses are. The team estimates a combined mass for PG 1302–102's pair of a few hundred million solar masses; the individual masses are unknown but are likely comparable.

Astronomers still don't have a good handle on what happens in the final few light-years of a black hole merger, but PG 1302–102's (purported) black holes will likely merge in a few hundred thousand to a couple million years.

■ CAMILLE M. CARLISLE & MONICA YOUNG



This image of Comet 67P/Churyumov-Gerasimenko reveals a large fracture, roughly 500 metres long, running through the nucleus. ESA / ROSETTA / MPS FOR OSIRIS TEAM

COMETS I Rosetta reveals Comet 67P

Scientists with ESA's Rosetta mission have released their summary of the first two months of observations of Comet 67P/Churyumov-Gerasimenko, reported in seven articles published January 23 in *Science*. Arguably, the most far-reaching discovery was that 67P's water molecules have a deuterium-to-hydrogen ratio far higher than that in Earth's oceans, suggesting our planet's water doesn't come from comets. But five other details about the nucleus are particularly intriguing.

First, the narrow waist that joins the nucleus's two lobes (one 4.1 km long, the other 2.6 km long) has to date been the source of most of the comet's escaping gas and dust. It's unclear whether the comet assembled as two large masses or if its midsection was once much plumper but has eroded away.

Second, the nucleus is very dark overall, with an average reflectivity of just 6% — nearly black, much like charcoal. This jibes with the albedos found for Comet 9P/Tempel 1, 103P/Hartley 2, and 1P/Halley. In comparison, the Moon's average albedo is 12%. The blackness likely comes from a veneer of dust particles that were originally launched with rapidly escaping gas but then settled back onto the surface in an even coating as the comet spun.

Third, based on how strongly it attracts Rosetta, the nucleus must have a mass of about 10 billion tonnes. But the comet's overall density is just 0.47 g/cm3 — similar to wood. The ice-and-rock interior must be very 'fluffy,' with a porosity of 70% to 80%.

Fourth, scans by Rosetta's VIRTIS instrument haven't found any ice on the comet's surface, contrary to what's seen on other Jupiter-family comets. Instead, the dark exterior is covered with complex, carbon-rich organic molecules. It's possible that these compounds are polycyclic aromatic hydrocarbons (PAHs) — much like the stuff coating the dark half of Saturn's moon Iapetus.

Fifth, the surface is a wonderland of weird landforms. The OSIRIS team has subdivided Comet 67P into 19 regions (all named for ancient Egyptian deities) that correspond to five distinct terrain types: smooth, brittle with pits and circular structures, large depressions, dust covered and consolidated ("rock-like"). For example, Hapi (the god who made the Nile River flood each year) is the smooth terrain in the neck that has dominated the comet's outgassing. Gas-spewing pits dot the region called Seth (a violent god associated with storms and disorder). Elsewhere the camera recorded enigmatic mounds, about 3 metres across, which the team calls "goosebumps."

■ J. KELLY BEATTY

IN BRIEF

Ancient five-planet system found. Astronomers have confirmed a five-planet system around the 11 billion-year-old star Kepler-444 (HIP 94931, in the constellation Lyra). With estimated sizes ranging from 0.4 to 0.7 times Earth, all five should be rocky, but not one is in the star's habitable zone: they all orbit the red dwarf within 0.08 astronomical unit, or less than one-fifth the size of Mercury's orbit. An optimistic habitable zone would start at 0.47 a.u., nearly six times farther out, Tiago Campante (University of Birmingham, UK, and Aarhus University, Denmark) and colleagues report in the February 1 *Astrophysical Journal*. Kepler-444 is not the first star of this age with planetary children: astronomers have also found two planets around Kepler-10 (10 billion years old) and two planets around Kapteyn's Star (11 billion years old). But those planets are super-Earth-size or larger.

■ CAMILLE M. CARLISLE

Citizen scientists find disks. Volunteers with Disk Detective have found 37 planet-forming disk candidates for follow-up study. (A disk is the swirling cloud of gas and dust that surrounds a young star, and from which planets are thought to form.) Led by Marc Kuchner (NASA Goddard) and the Zooniverse team, Disk Detective uses data from the Wide-field Infrared Survey Explorer (WISE) satellite, which found hundreds of thousands of infrared sources that could be disks around nearby stars — or far-off galaxies, interstellar dust clouds or other extended infrared sources. Volunteers can classify each of the 278,000 infrared sources after a brief tutorial at www.diskdetective.org. Thus far they've turned up 478 'objects of interest' (possible disks) and 37 strong candidates. The strong candidates range in distance from 80 to 3,300 light-years. By 2018 the project should net more than 1,000 disks.

■ MONICA YOUNG

A new world to explore

What will we call features on Pluto and its moons?

What names will we apply to features found on Pluto and its moons? ARTIST'S IMPRESSION COURTESY IAU / L. CALÇADA

In March, the International Astronomical Union (IAU), the SETI Institute and the New Horizons team, put out a call to the public for suggestions on what to name the Plutonian features that are bound to jump out of the images New Horizons sends back.

The world of astronomy and Solar System science has long-established conventions on how celestial bodies are named, who gets to name them, and what those names should be. For instance, did you know that – with only three exceptions – every geological feature on Venus is named after females, either real or mythological?

For the Pluto system, during a very limited two-week period at the end of March and beginning of April the public was invited to vote for their favourite names, which might be applied to mountains, craters, valleys and so on, as well as any extra moons that New Horizons might find.

Names associated with Pluto itself have to be drawn from: names for the 'underworld' from the world's mythologies; gods, goddesses and dwarves associated with the underworld; heroes and other explorers of the underworld; and writers, scientists and engineers associated with Pluto and the Kuiper Belt.

For Pluto's largest satellite, or moon, Charon, the names must be: destinations and milestones of fictional space and other exploration; fictional and mythological vessels of space and other explorations; and fictional and mythological voyagers, travellers and explorers.

For Pluto's four other known moons, the choices are simpler. For Styx, it is river gods. For Nix, deities of the night; Kerberos, dogs from literature, mythology and history; and for Hydra it is legendary serpents and dragons.

But some naming themes are not appropriate for Pluto, as they've already been used for Mercury, Venus and Mars: space missions and spacecraft names; authors, artists, directors and producers of the fiction of exploration; and explorers of the Earth, air and seas.

The conventions for all of these naming schemes are set down by the IAU's Working Group for Planetary System Nomenclature (WGPSN). Although the public's votes will be taken into account, the IAU has the final say.

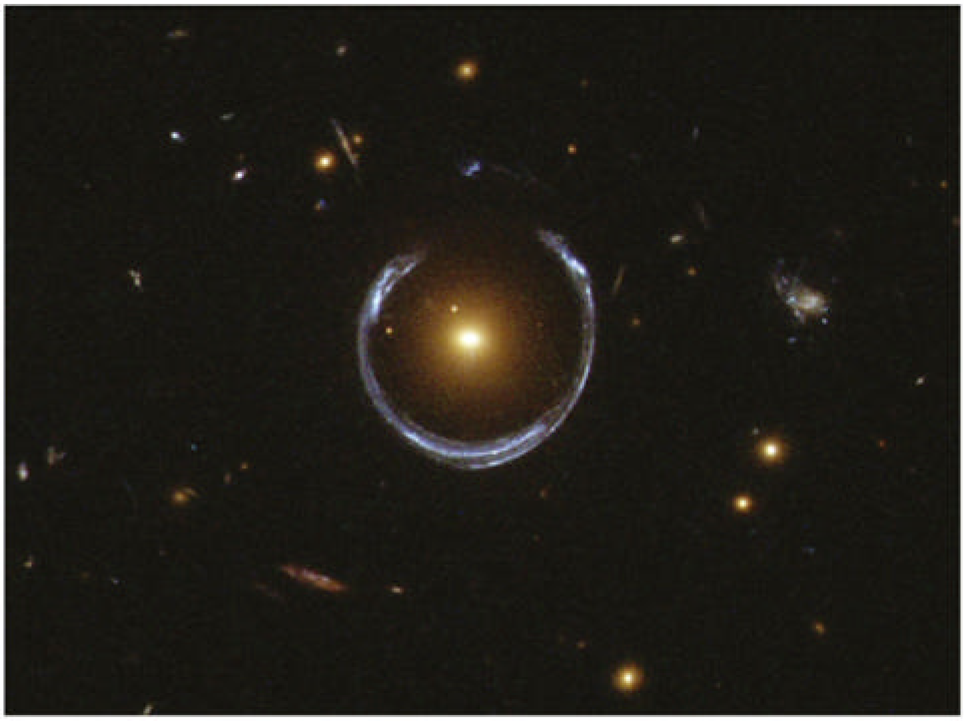
Oh, and what about those three non-female names on Venus? Well, one of them is Maxwell Montes, or Mount Maxwell, named after James Clerk Maxwell, the 'father' of classical electromagnetic theory, whose work to radar and just about every other electronic device or technique we use today. It was through radar that we got our first hint at what lies below the Venusian clouds. The other two names are Alpha Regio and Beta Regio – or region A and Region B – detected in the early radar surveys. ✦

Relativity put to the test

A total eclipse of the Sun cemented Einstein's reputation

In 1905, Albert Einstein was an obscure clerk in a patent office in Berne in Switzerland. Fifteen years later he was the most famous scientist in the world, with his picture on the front pages of the leading newspapers. In the years between those dates his reputation had grown enormously among the scientific community, though not everyone accepted his radical ideas. A remarkable series of four scientific papers that he published in 1905 had transformed the way physicists viewed the workings of the universe. The Nobel Prize for Physics was to come in 1920.

The astronomical event that brought him so forcibly to wider public attention would occur on May 19, 1919, when a total eclipse of the Sun would be visible across the South Atlantic from South America to Africa. An expedition was sent from Britain to observe the eclipse, headed by the leading astronomers Arthur Eddington from Cambridge University and Frank Dyson, the latter being the Astronomer Royal. The group split into two teams: Dyson's took his half of the team to Sobral in Brazil; Eddington and company set up camp on the island of Principe off the west coast of Africa.



The gravity of a foreground galaxy distorts the light of a distant background galaxy into an almost-complete 'Einstein Ring'. ESA / HUBBLE / NASA

During a total eclipse of the Sun, the stars lying close to the sun in the sky, normally hidden by its glare, become visible. During that few minutes of darkness, their positions can be measured, and later compared with their position at night when far from the Sun. As one of the consequences of his Theory of General Relativity, which he had published in 1915, Einstein had argued that the positions of those stars on the two occasions would be slightly different. In his theory gravity can bend the path of a ray of light — stated more strictly, the presence of mass, or energy, can curve space-time in its vicinity, and the light rays taking the shortest path through that space time, would appear curved. The path of rays of starlight passing close to the edge of the eclipsed Sun would therefore be bent, appearing to displace the stars from which they came fractionally from their true positions.

The two teams worked independently, making their observations and analysing the results. Eddington had a lot of trouble with the weather at his viewing position and was able to measure only five stars. Dyson did rather better. When they came together to compare their findings, they seemed to confirm what Einstein had predicted. Eddington declared Einstein's bold conjecture proven and the discovery made headline news around the world. Einstein's reputation was established.

Einstein himself had not doubted his prediction. He reputedly said when asked what he would think if the expedition had not confirmed his result, "I would be sorry for the dear Lord. The theory is correct".

But the confirmation was not as unequivocal as Eddington had claimed, and not everyone was convinced. The anticipated bending was very small, less than two seconds of arc, roughly equivalent to the diameter of two five cent coins when viewed at a distance of two kilometres. Instrumental error had to be taken into account together with the unsteadiness of the atmosphere, and perhaps even the impact of 'confirmation bias', in which the observer can (perhaps unconsciously) interpret observations to confirm a theory that they already accept to be true, or exclude those which do not seem to fit. Eddington in particular was keen to have Einstein supported, while Dyson was more skeptical.

Given the uncertainties, some argued that the observations did not conclusively support Einstein's prediction against one calculated on the basis of Newton's theory of gravity (which Einstein was reputedly displacing). But history has come down on the side of the 1919 conclusion. Similar observations have been made on a number of other occasions, and in recent years they have been done using radio waves, observations that do not need a solar eclipse to blot out the sunlight. The results are very much in line with Einstein's predictions, clearly supporting his theory against that of Newton.

Now as further support we have the phenomenon of 'gravitational lensing', in which the intense gravity of a cluster of galaxies can bend the light from objects even further away, acting like a lens and forming distinctive curved images which can take the form of a ring — an 'Einstein ring'. No one can now doubt that Einstein's post-1919 reputation is well deserved. ✦

David Ellyard **presented SkyWatch on ABC TV in the 1980s. His StarWatch StarWheel has sold over 100,000 copies.**

Night Flight

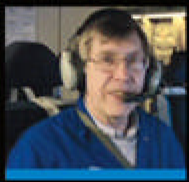
Astronomy aboard SOFIA

After two decades of trials and tinkering, the Stratospheric Observatory for Infrared Astronomy (SOFIA) is finally flying high.

'First Class' here isn't exactly posh — the cloth-covered seats date from the 1980s, it's cold and noisy, and there's no food service or even hot coffee. But that's not why I've boarded this repurposed Boeing 747SP aircraft. On tonight's red-eye over the Pacific Ocean, it's all about the in-flight entertainment: a chance to see the universe in ways that just aren't possible from the ground.

SOFIA, the Stratospheric Observatory for Infrared Astronomy, soars to altitudes at or above 12 kilometres (39,000 feet). From these heights, above 99% of the atmosphere's infrared-blocking water vapour, the craft's compact, 2.5-metre telescope can be trained on targets in the 'warm universe' — anything from nearby asteroids to star-forming regions in remote galaxies.

NASA acquired this 747SP in 1997 from United Airlines, which in turn had bought it in 1986 from the now-defunct airline Pan Am, which had flown it since 1978. The gleaming white fuselage is still emblazoned with Clipper Lindbergh, the plane's original name, but nothing of the once-opulent interior remains. It took nearly a decade and $800 million for contractors to gut the interior and install the telescope, which was fabricated by the German Aerospace Center (DLR), NASA's partner for this project. Day-to-day operations are managed for NASA by Universities Space Research Association (USRA).



J. KELLY BEATTY

The telescope itself is open to the air at high altitude and hidden behind a thick bulkhead that isolates it from the crew compartment. The telescope looks out through a gaping, 5.5-by-4.1-metre hole in the aircraft's port (left) side.

NASA's Stratospheric Observatory for Infrared Astronomy takes off from Palmdale, California, at sunset to begin a full night of astronomical observations.
NASA / CARLA THOMAS

It can tilt up and down to elevations from 20° to 60° above horizontal. Pointing in azimuth is done by turning the whole airplane. A sliding door covers the opening until it's time to observe, and a spoiler on the hole's leading edge reduces turbulence.

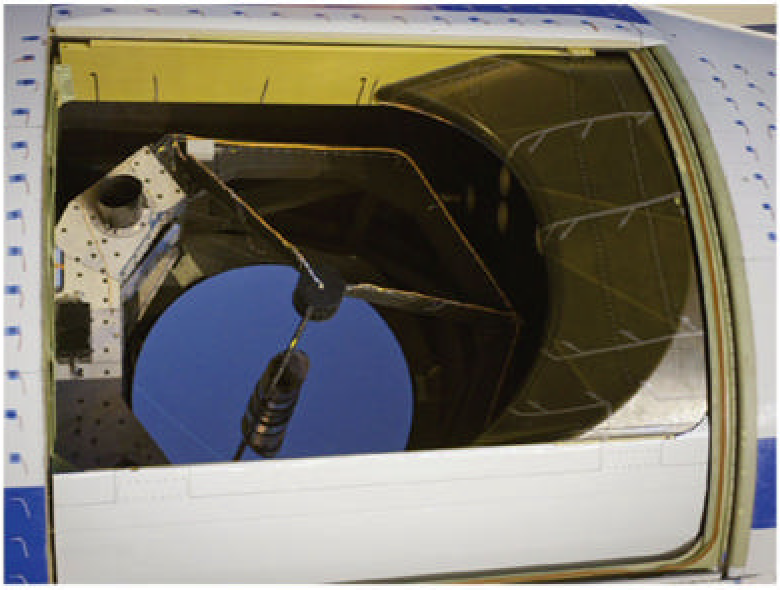
Jutting from the bulkhead into the pressurised cabin are the telescope's focal plane, a massive counterweight, and FORCAST, a beefy Cornell University-built camera that records a small patch of sky 3.2 arcminutes square. FORCAST is equipped with 13 mid-infrared filters spaced in wavelength between 5 and 40 microns, or about 10 to 80 times the wavelength of visible (green) light. It also has six grating prisms ('grisms') to spread the incoming infrared light into spectra. Liquid nitrogen keeps the detector array cryogenically chilled, so that its own infrared glow doesn't overwhelm its view of the sky.

Instrument scientist Andrew Helton runs through the night's target list with me:

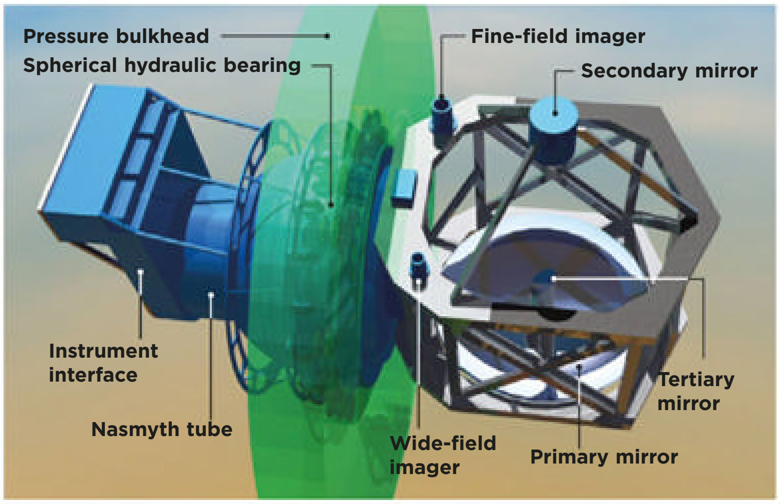
- U Monocerotis, a dying supergiant star, is an RV Tauri type of pulsating variable. Observers want to know more about the shells of dust that it has ejected.
- VY Canis Majoris, a red hypergiant star with 40 times the Sun's mass, is sometimes cited as the largest star known, larger than the orbit of Jupiter. Its past eruptions can be analysed by recording the faint shells of cool dust surrounding it. "A difficult observation," Helton cautions.
- NGC 3501, an edge-on spiral galaxy in Leo, will be scanned to see how much dust has settled to its midplane versus how much is distributed above and below the disk.
- Asteroid 2 Pallas is on the list for two reasons. This reddish object serves as a calibration target, and Franck Marchis (SETI Institute), who's aboard, also wants to probe the dust layer on its surface.
- The night's main attraction is the Cigar Galaxy (M82) and specifically SN 2014J — the brightest supernova in decades — blazing in its disk. Astronomers had captured the outburst with another instrument on a prior SOFIA flight, but tonight a trio of observers led by William Vacca (USRA) hopes to record an emission line at 11.9 microns. This is from doubly ionised cobalt atoms in the blast wave; cobalt is a decay product from the radioactive nickel-56 synthesised in the stellar explosion, and this decay keeps supernova shells glowing brightly for months after they explode.

Vacca says it's a challenging observation: look for the cobalt emission too soon after the star explodes, and the supernova's expanding shell will be too opaque; look too

NASA / JIM ROSS

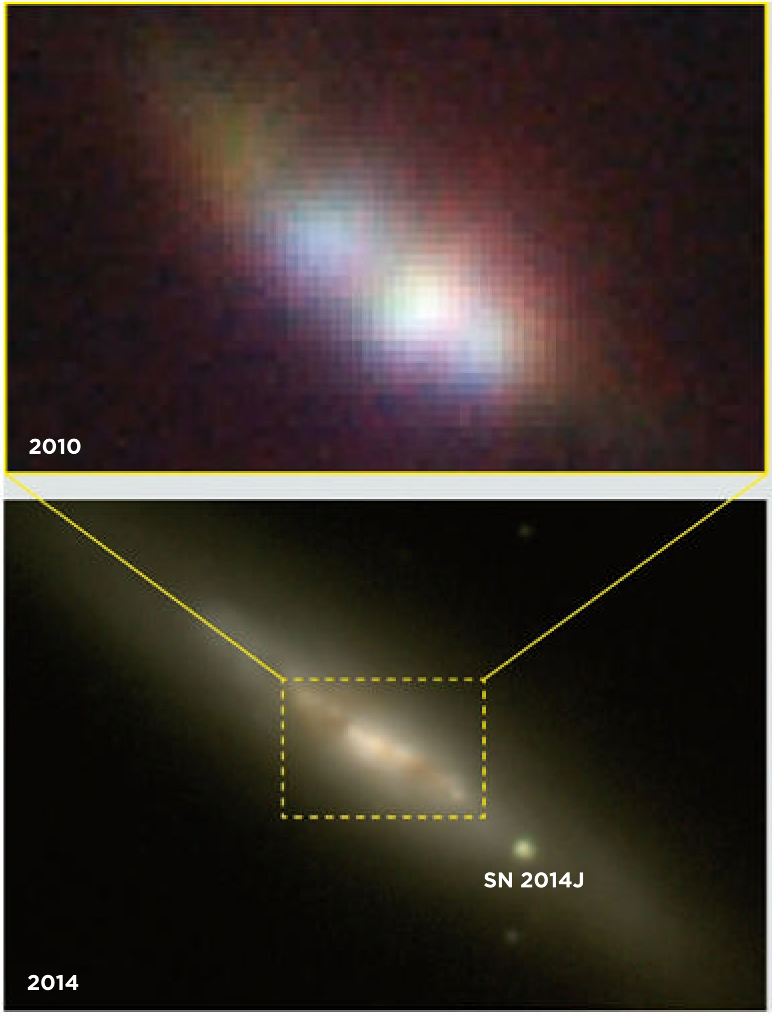


NASA / TOM TSCHIDA



DAVID BLACK / ROSIE BUHRLEY

Top: **A jet aircraft with a huge rectangular opening in its fuselage is an unlikely sight. This view of SOFIA over remote California terrain was taken during test flights in 2010.** ***Middle:*** **The telescope looks out through a 5.5-by-4-metre opening in the fuselage, which is covered by a huge sliding door until the plane reaches high altitude. A thick bulkhead separates the telescope compartment from the passenger cabin and incorporates a huge spherical bearing, shock absorbers and gyroscopes to control the telescope's motion.**



Science from SOFIA

SOFIA's telescope is modest compared to the giants at modern ground-based observatories, but the latter are limited to viewing only in a few near-infrared wavelengths due to atmospheric absorption. Meanwhile, infrared-sensing space telescopes such as Spitzer and Herschel, having run out of cryogenic coolant, can no longer record the longer-wavelength radiation from very cold cosmic sources.

That leaves SOFIA in a unique position to collect images and spectra throughout the infrared spectrum: at wavelengths from 1 to 1600 microns. Since the plane's 'first light' flight in mid-2010, astronomers have used it to probe scores of targets. U.S.-funded research takes up 80% of the flight hours, while German astronomers get 20%. SOFIA's instruments are typically used in rotation, each getting bolted to the telescope for several flights before mechanics switch it out for another.

Eight reports of early science results from the flying observatory were showcased in a special 2012 issue of *Astrophysical Journal Letters*. More recently, both FORCAST and FLITECAM were used to record Supernova 2014J, and over the next year astronomers will use SOFIA to study a wide range of planetary atmospheres, interstellar clouds, protoplanetary disks and ejected matter from novae and supernovae.

***Upper left:* The heart of the Cigar Galaxy, M82, was an early target for SOFIA and its FORCAST camera at wavelengths of 20, 32, and 37 microns. Left: The near-infrared view of M82 — and Supernova 2014J — captured by the FLITECAM instrument.** NASA / FORCAST SCIENCE TEAM / FLITECAM SCIENCE TEAM (2)

late, and the cobalt will have spread out too far and become too dim. "We're hoping it's the right time," he says. The flight plan calls for SOFIA's telescope to stare at SN 2014J for nearly three hours.

Take-off is scheduled for 6:37 p.m. I settle into one of the vintage first-class seats as the Sun lingers over the western horizon. But murmuring in the cabin signals that something is amiss. Soon flight director Randy Grashuis gathers everyone and delivers the bad news: there's an errant flap sensor in the cockpit display. The flap itself is OK, but the sensor is dead. Unless a replacement is found fast, tonight's flight will be scrubbed.

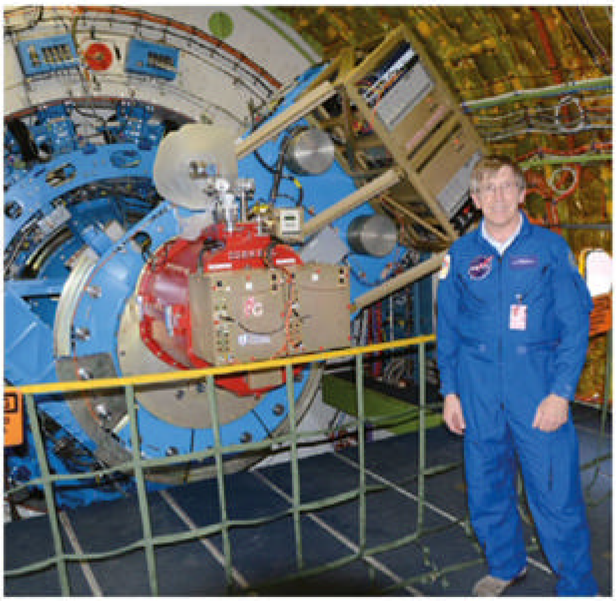
"Not again!" I groan.

My efforts to ride SOFIA go back to 2011, when I'd watched three chances come and go. Too much rain foiled the first attempt, and a schedule mismatch scuttled the second. For the third try, I headed to SOFIA's home base, NASA's Dryden Aircraft Operations Facility in Palmdale, California, and completed all the requisite preflight training for that evening's flight. Then it snowed — in the Mojave Desert! The flight was cancelled because DAOF, understandably, has no snowplows.

SOFIA was grounded the following year for a series of equipment and electronics upgrades. Undaunted, I strapped in for a flight in March 2013. But an hour after takeoff, low oil-pressure warnings in two engines forced an early return to Palmdale.

In three years of trying, I am 0-for-5 — and now my Flight Attempt Number 6 isn't going well either.

Fortunately, standing idle on the tarmac nearby is one of NASA's other 747s, once used to ferry Space Shuttles piggyback across the country. Mechanics raid its cockpit for the needed part and make the swap in



The author poses with the business end of SOFIA's telescope: the bulkhead, Cornell's half-ton FORCAST camera/spectrometer, and a counterweight at top centre containing racks of electronics. *S&T:* J. KELLY BEATTY

> **The plane makes a beeline for the coast and, after threading a narrow corridor between restricted airspaces, heads out over the Pacific Ocean.**

record time. The plane's tyres finally lift off the runway at 8:56 p.m. — just minutes before the flight would have been scrubbed.

Time management

We're airborne, but we've lost nearly 2½ hours of flying time — and compromises must be made. While the mechanics were preoccupied with the flap sensor, science flight planner Karina Leppik and copilot Wayne Ringelberg had huddled tensely around a computer display of possible reroutings. Their eventual Plan B preserves the observations of VY CMa, Pallas, and SN 2014J, along with an hour of staring at Arcturus as a calibration target. Losing out, tonight at least, are U Mon and NGC 3501.

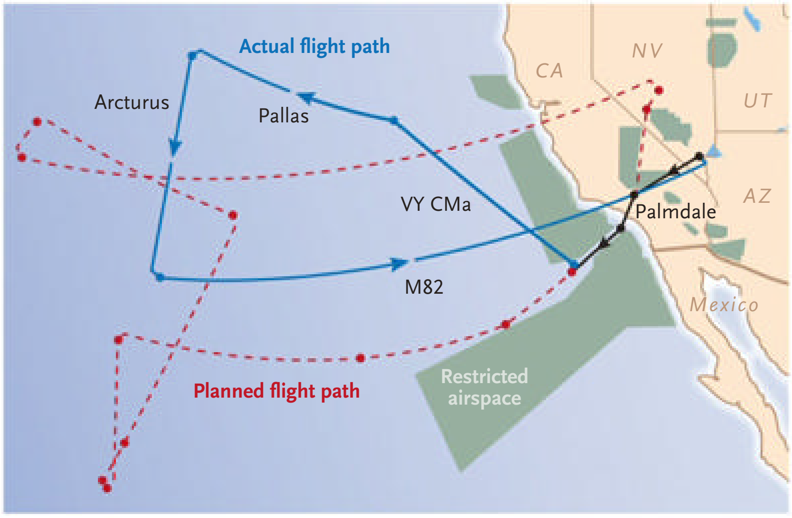
The plane makes a beeline for the coast and, after threading a narrow corridor between restricted airspaces, heads out over the Pacific Ocean for the first of five long legs that will take until nearly dawn to complete. Everyone settles in for the all-nighter ahead.

After passing through about 30,000 feet, Grashuis makes the call to slide open the giant barrel door in the fuselage. I expect to hear a deep-throated whoosh or feel some vibration to signal that stratospheric air is rushing past a huge hole in the plane's side at Mach 0.85. But nothing like that happens — in fact, the only indication that the door really has opened is a graphic on one of the computer monitors.

A glance aft at the big bulkhead shows the focal plane, counterweight, and FORCAST moving slightly, up and down, side-to-side. But in reality the 17-ton telescope's pointing is rock-solid, steadied to 0.35 arcsecond in some modes; the gentle nodding actually betrays the slight pitch, yaw, and roll of the plane around it.

The 2.7-m primary mirror has an effective aperture of 2.5 m because of its large secondary and other factors, and the overall optical path is f/20. The atmospheric seeing out the door typically limits resolution to 2 to 4 arcseconds even at altitude. That would be a problem for a visual observer back on Earth, but deep in the infrared, it's less than the diffraction limit for a telescope of this size at wavelengths greater than 15 microns.

S&T: J. KELLY BEATTY

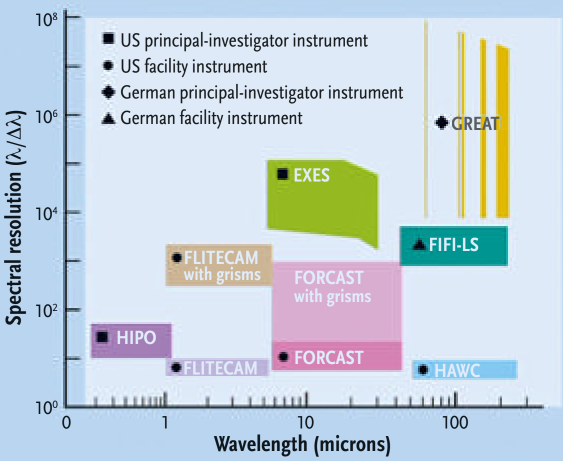


S&T: LEAH TISCIONE, SOURCE: USRA / KARINA LEPPIK

S&T: J. KELLY BEATTY

Top: Science flight planner Karina Leppik and copilot Wayne Ringelberg work out a new flight plan after takeoff was delayed by more than 2 hours. *Middle:* Because the telescope stares out the port (left) side of the fuselage, SOFIA's pilots must execute a convoluted flight plan to put all the night's targets within view. This plot shows the original itinerary (red) and the abbreviated routing (blue) necessitated by a delayed takeoff. Green polygons denote restricted airspace. *Bottom:* Parked near SOFIA's hangar is one of two 747 aircraft that NASA once used to ferry Space Shuttle orbiters across the country.

SOFIA's Instruments: Eyes on the Infrared Sky



Abbrev.	Name	Institution	Wavelengths (microns)
EXES	Echelon-Cross-Echelle Spectrograph	UC Davis	4.5 – 28 µ
FIFI-LS	Field Imaging Far-Infrared Line Spectrometer	Univ. of Stuttgart	50 – 200 µ
FLITECAM	First Light Infrared Test Experiment Camera	UC Los Angeles	1 – 5 µ
FORCAST	Faint Object Infrared Camera for the SOFIA Telescope	Cornell University	5 – 40 µ
GREAT	German Receiver for Astronomy at Terahertz Frequencies	Max Planck Institute	60 – 200 µ
HAWC	High-resolution Airborne Wideband Camera (ready in 2016)	Jet Propulsion Lab.	50 – 240 µ
HIPO	High-speed Imaging Photometer for Occultations	Lowell Observatory	0.3 – 1.1 µ

Astronomers flying on SOFIA can make their observations using one of several instruments designed to probe different parts of the infrared spectrum. Two additional instruments are under construction. In the chart, Spectral Resolution denotes how finely the target's infrared spectrum is recorded.
S&T: LEAH TISCIONE, SOURCE: NASA / USRA

We zigzag our way over the open ocean, completing the VY CMa and Pallas legs. There's a deceptive calm in the cabin, as 13 scientists and operators stare intently at the displays on their consoles. Tight time constraints mean the observing sequences have to be accomplished quickly and efficiently. "It's a completely new way to observe," one first-time researcher tells me, "with a level of anxiety and nervousness I've never had before."

Four hours into the flight, we turn eastward for the long stare at M82. The recast flight plan has preserved almost all of this critical observation, because FORCAST will need every photon it can get to detect the weak cobalt emission line. In the end, however, even 140 minutes of dedicated staring wasn't enough. "Unfortunately, the supernova wasn't detected," Vacca admits. "It's simply a case of the line being too weak to detect with a smallish telescope in the presence of the atmosphere's strong background — even from SOFIA."

By now we've cleared the coastline, and the predawn lights of Las Vegas twirl below as SOFIA makes the turnaround that leads back to Palmdale. I head to the surprisingly cramped cockpit to watch the pilots execute the final approach. We land in darkness, with dawn's early glow just breaking in the east.

Riding out some turbulence

The pilots and crew make it look easy, but getting SOFIA to this point has been far more challenging than originally envisioned. The project began back in 1997, but the repurposed plane didn't make its initial test flight until mid-2007, and its telescope finally feasted on starlight while airborne three years later. Paul Hertz, who heads NASA's astrophysics program, didn't declare SOFIA fully operational until June of last year.

Soon afterward the plane was flown to Hamburg, Germany, for six months of 'heavy maintenance' performed by Lufthansa Tecknik and DLR. Technicians removed the engines and stripped away panels to check for corrosion and cracks in the 36-year-old airframe. Science flights are again happening regularly now, and more than 70 observing proposals are queued up for 2015.

Observers appreciate SOFIA's ability to let them ride along with their experiments and fine-tune filter settings and exposure times on the fly. The plane's mobility also makes it possible to observe any target on the celestial sphere — as demonstrated during a two-week stint in 2013 when it flew to New Zealand to concentrate on the far-southern sky — or to capitalise on targets of opportunity such as SN 2014J.

But it's a very expensive operation, with an $80 million budget in fiscal year 2014. That's more than $100,000 per hour of actual research at altitude. "Unlike a space mission," Hertz explains, "SOFIA doesn't get cheaper to operate after launch." In fact, despite the unique capabilities that a flying observatory affords, some astronomers question whether SOFIA's scientific productivity will ever justify the $1.1 billion development cost — more than three times the original estimate.

SOFIA FAST FACTS

- One of 45 747SP aircraft built; only 14 are still flying
- Maiden flight: April 26, 2007; telescope's first light: May 26, 2010
- Wingspan (59.7 metres) exceeds length (56.4 metres)
- Mass at takeoff: 315,700 kg
- Range: 12,270 kilometres
- Mission duration: 7 to 9 hours (12 hours maximum)
- Telescope port door: 5.5 by 4.1 m
- Telescope: 15,500 kg; f/19.7 optics
- Primary mirror: Schott Zerodur; 2.7 m (oversize) f/1.3

The 747's cockpit, updated from the 1978 original, is an orderly array of gauges and controls.
NASA / CARLA THOMAS

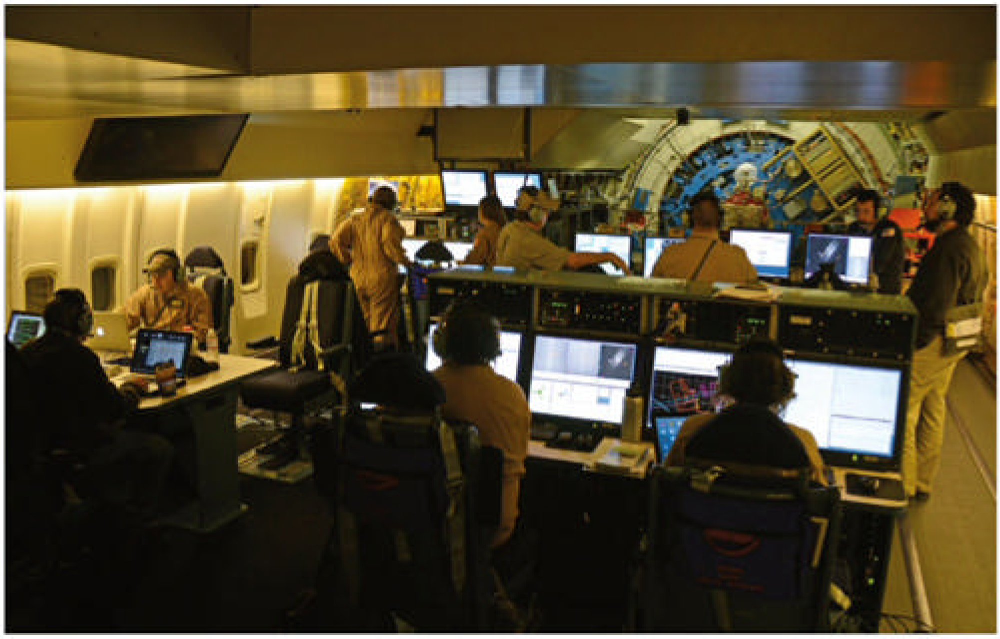
As one measure of the project's uncertain standing, last year the Obama administration proposed mothballing the plane for an undefined period beginning in fiscal 2015 as a part of overall budget-tightening at NASA. The space agency even started looking for other agencies to take over SOFIA's operation. But supporters in both the House and Senate countered with $70 million in extra funding to ensure that NASA keeps the flights coming for another year. DLR officials were understandably relieved.

However, the scrutiny continues. In July 2014, NASA's Office of Inspector General investigated the program's operational challenges and recommended 10 changes. For example, the OIG found there's not enough planning for future technological upgrades, no mechanism for rescheduling missed opportunities (such as the U Mon and NGC 3501 targets on my flight), and a backlog of undelivered observations after flights are over (example: Marchis is still waiting for his Pallas data).

Meanwhile, Hertz plans to launch a 'senior review' of the SOFIA program this year. Outside experts will look at ways to maximise the science return. "Hours cost money," Hertz explains, "and the right choice might be to fly fewer hours." They'll also explore ways to restructure AURA's operations contract, which expires next year. Most critically, they'll assess SOFIA's scientific relevance when judged against other agency programs and funding needs.

But Hertz also emphasises that SOFIA gives astronomers regular access to a little-explored slice of the electromagnetic spectrum. Seven instruments are in the observational rotation now, and two more (one German, one American) will be in the mix by the end of next year. "We have not stopped moving forward," he insists. With luck — and steady funding — this one-of-a-kind flying observatory will still be soaring into the stratosphere 20 years from now. ✦

Senior editor *Kelly Beatty* made his first flight on SOFIA's predecessor, NASA's Kuiper Airborne Observatory, in 1988.



The aircraft's roomy but cold and noisy cabin has workstations for four specific tasks: the flight manager and science planner (seated at right, foreground); astronomers (far left); telescope operators (just left of centre); and instrument control (right of centre). Everyone faces aft toward the pressure bulkhead and telescope compartment (upper right, background). Some astronomers choose to come aboard to oversee their observations. The lucky ones get to take their data early and then catch up on sleep after SOFIA turns to view other targets. S&T: J. KELLY BEATTY (2)

Dawn arrives at Ceres

NASA's spacecraft has entered into orbit around the largest asteroid in the main belt.

EMILY LAKDAWALLA

It was once called a planet, and then it was summarily demoted. Long passed over for larger Solar System targets, this dwarf planet remains mysterious, with an unknown composition and origin. But the mystery won't last long: this year, a long-voyaging spacecraft is finally paying the neglected world a visit.

I could be discussing Pluto, but I'm not. Ceres, the first-discovered and largest of the asteroids, is the second target of NASA's Dawn mission. Having arrived at Ceres, Dawn has become the first spacecraft ever to orbit (not just fly by) two worlds beyond Earth.

Dawn is a little spacecraft with a huge wingspan. The spacecraft's small cubical body can mostly hide behind its 1.5-metre-wide dish antenna, but its solar panels stretch nearly 20 metres from wingtip to wingtip. Dawn needs huge solar panels for two reasons. One is distance. Out at Ceres' orbit within the main asteroid belt, the Sun shines only 13% as strongly as it does on Earth. Only two solar-powered missions operate at greater distances from the Sun than Dawn does: the European Space Agency's Rosetta, in orbit around Comet 67P/Churyumov-Gerasimenko, and NASA's Juno, on its way to Jupiter.

The other reason is thrust. The Sun gives Dawn electricity for free, electricity it can use to accelerate xenon ions to enormous speeds, 7 to 10 times faster than the speed of exhaust from traditional chemical engines. At maximum thrust, each of Dawn's three ion engines expels a miniscule 3.25 milligrams of xenon per second. The resulting thrust is only 91 millinewtons, the same force with which a single sheet of paper weighs on your hand. It's now even less (down to less than 30 millinewtons), for as Dawn's solar separation increases, the solar panels produce less electricity and the engines less thrust. But the patient and near-continuous work of the electrically accelerated ions has propelled Dawn into the record books: it has achieved more change in speed under its own power than any previous spacecraft (10.7 kilometers per second, or 38,450 kph, by the time it reached Ceres).

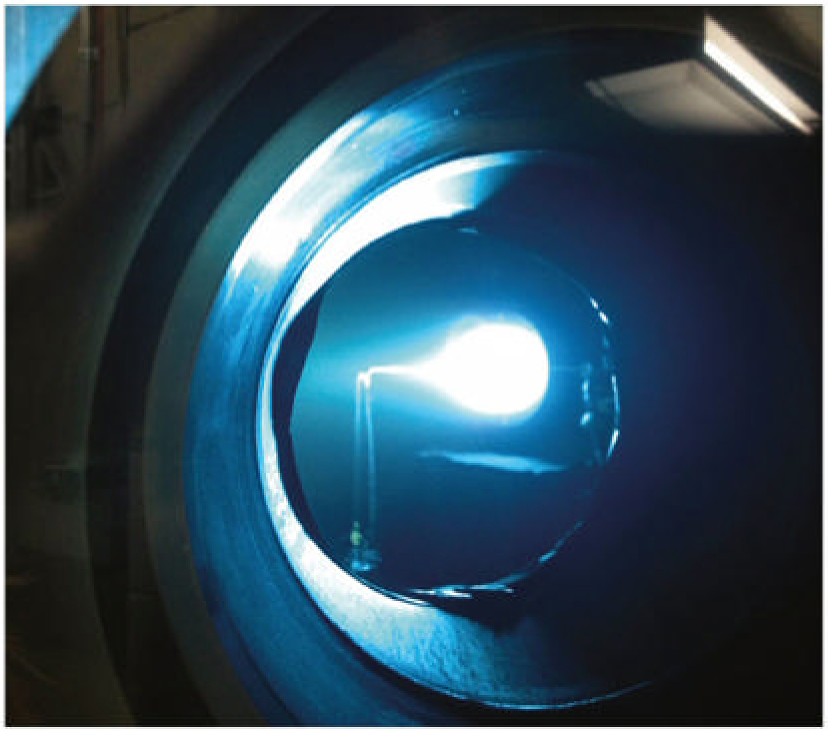
It's Dawn's ion propulsion system that makes the mission's two-world navigational feat possible. Having opened our eyes to the marvels of Vesta, the little spacecraft that could has homed in on a world like none we've seen before. Ceres' size, roundness and water-rich composition make it seem a kin of Pluto, yet it orbits among the scattered lumpy asteroids. Is it a protoplanet? An escaped Kuiper Belt object? What, if anything, can it tell us about how the Solar System formed?

Vesta success, flywheel failure

Dawn launched from Earth in September 2007 and received a boost from a Mars flyby in February 2009. It settled into orbit at Vesta on July 16, 2011, and kept the asteroid company for about a third of its year, until September 5, 2012. Then, Dawn departed Vesta — a rare feat. Only one other mission that has ventured beyond the Moon has ever departed from its deep-space orbital destination: the first Hayabusa mission (also ion-powered), which rendezvoused with Itokawa in September 2005 and departed that December to return to Earth.

Dawn transformed Vesta from a smudge of light into a world with complex geology. Its measurements

DAWN APPROACHES NASA's Dawn spacecraft bears down on Ceres, the largest main-belt asteroid in the Solar System, in this artist's illustration.



FULL THROTTLE Although Dawn's xenon ion engine (shown here in the lab) produces a small amount of thrust, that thrust built up over time, eventually propelling the spacecraft to a velocity of about 11 kilometres per second. NASA / JPL-CALTECH

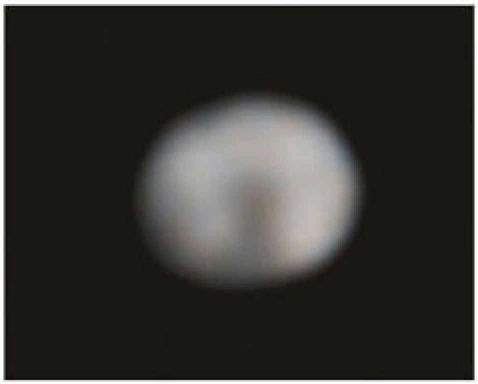
confirmed that the asteroid has separated into a denser, perhaps metal-rich core and a less-dense rocky mantle and crust. This differentiation is a major driver of internal geology, and planets and moons that are differentiated are also usually round and would therefore be classified as dwarf planets. But after it differentiated, Vesta suffered two enormous impacts, both near the south pole, which left huge scars on its three-dimensional shape. An enormous mountain sticks out of its south pole, and its equator is girdled with rhythmic troughs — fossil waves from an impact that nearly blew Vesta apart.

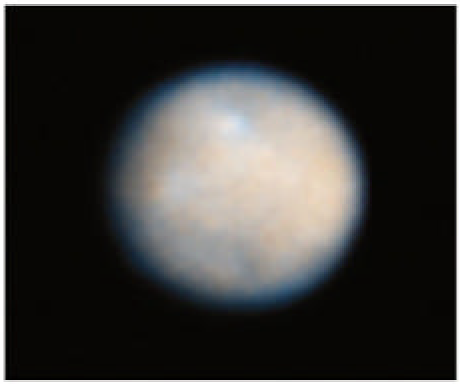
One of the most intriguing features Dawn saw at Vesta was so-called 'dark material' in splotches and sprays found across much of its surface (but not inside the largest south polar impact basin, Rheasilvia). That dark material contains hydrated minerals and might be carbon-rich. Neither of those types of compounds would have formed where Vesta now orbits, so the dark material probably represents stuff that originally formed much farther away, perhaps beyond Neptune. Any such material that hit Vesta should also have struck Ceres and all the other asteroids.

Given Dawn's innovative propulsion system, it's ironic that the mission was jeopardised by one of humanity's oldest technologies: the wheel. In June 2010, on approach to Vesta, one of Dawn's four reaction wheels failed. These devices enable the spacecraft to maintain its orientation in space, to keep its solar panels facing the Sun, its dish antenna pointed at Earth, and its instruments aimed at science targets. Because reaction wheels are spun using electricity generated by the solar panels, pointing with reaction wheels is essentially without cost to the mission — unlike the spacecraft's rockets, which have a limited supply of hydrazine to power them.

After the loss of the first reaction wheel, mission controllers scrambled to conserve hydrazine and preserve the three remaining reaction wheels by using them sparingly. They completed the Vesta mission with three wheels, but a second one ground to a halt as they prepared to depart Vesta in August 2012. Dawn could travel to Ceres without reaction wheels, but it was initially thought impossible to complete the Ceres mission as planned without them: there was simply not enough hydrazine to accomplish all of the required turns.

After a herculean effort, the mission's planners succeeded in finding a way for Dawn to complete its Ceres to-do list with no reaction wheels at all. They had to make some compromises: Dawn will not turn to talk to Earth as frequently as it did at Vesta, and imaged Ceres only 9 times as it approached, compared to the 23 imaging sessions it performed on approach to Vesta. But the spacecraft will actually gather more science data at Ceres than in the original plan.





HUBBLE VS DAWN Even Hubble can only resolve fuzzy images of Ceres and Vesta. Shown from left to right are Vesta as seen by Hubble in 2010, a mosaic of Vesta as seen by Dawn, and Ceres in a visible-UV composite from Hubble's view in 2003 and 2004.

Simply by being more patient and waiting a little longer to gather observations, mission planners will be able to acquire everything they promised to at Ceres, including full-colour global maps and detailed gravity data.

Another kind of water world

Ceres is a very different object from Vesta; we knew that already, even without visiting it. A key insight into Ceres is its density. Vesta has a bulk density nearly identical to that of silicate rock. Ceres is 80% larger but only two-thirds as dense as Vesta. Yet Ceres is too large for it to have much porosity (unlike smaller asteroids, which can have lots of void space, resulting in low density). There is only one plausible explanation: Ceres contains a substantial amount of water ice.

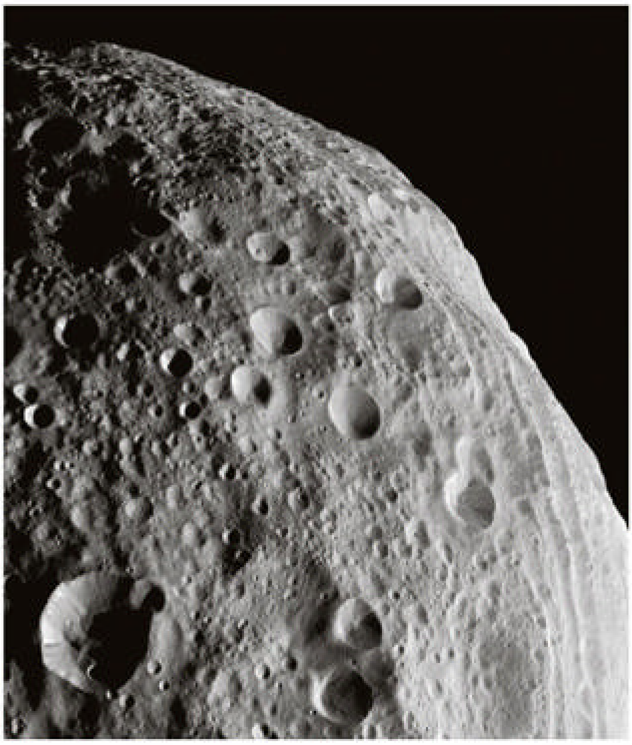
> **"Ceres' surface is too hot for ice to be stable anywhere except, possibly, at the poles. If there ever was any at the surface, it has sublimed away."**

Given the mass and dimensions of Ceres, and assuming initial proportions of elements like those found in meteorites, geophysicists Tom McCord (now at Bear Fight Institute) and Christophe Sotin (University of Nantes, France) simulated how Ceres would have evolved over time, from a newly condensed mixture of materials to the modern day, 4.6 billion years later. They found that Ceres almost certainly differentiated, its materials separating into a rocky core and watery mantle. Depending on how much of its water is incorporated into the crystal structures of its rocky minerals, its water could compose anywhere from 17 to 27% of its mass. The upper few kilometres of Ceres might always have been too cold for differentiation and so would have remained a mixture of ice and rock. But it's likely that there was a liquid internal ocean for some part of its history, and it's possible that such a liquid layer persists today.

But if this story were true, would there be evidence of it on the surface? Ceres' surface would always have been frozen solid, but as the body's primordial heat escaped, the dwarf planet would have cooled, its ocean slowly freezing solid from the top down. A primitive exterior could hide an evolved interior. On the other hand, any amount of rock in Ceres' crust would make it significantly denser than an icy mantle below it, which would be an unstable arrangement. Most likely, a primitive crust would founder and sink into the mantle, generating a fresh new surface on the asteroid.

An internal ocean could also drive very active surface geology. Ice is less dense than water, so as Ceres cooled and its subsurface ocean froze, the internal pressure would multiply as this material swelled and tried to take up more space. That internal pressure would have to be relieved somehow. The crust could have cracked in order to allow the mantle to expand, forming planetary stretch marks as a series of parallel fractures, like those we see today on Saturn's moon Dione. If such fractures propagated deep enough below the ground to open a conduit to the surface for the pressurised ocean, we could see frozen flows of cryovolcanic material, made of the mineral-rich stuff that once circulated deep within the body. In fact, with its icy composition and differentiated interior, Ceres will likely look much more like the moons of Jupiter or Saturn than it will look like Vesta.

Today, Ceres' surface is too hot for ice to be stable anywhere except, possibly, at the poles. If there ever was ice exposed at the surface, it has sublimed away. Any dust or rocky material that was once buried in the ice would remain on the surface, coating it in a darker, gunky lag deposit made of rocky silicates and organic material. But ice could be very close to the surface. Before it ran out of cryogen in 2013, the European Space Agency's infrared space telescope Herschel made the surprising discovery of water vapour in the space around Ceres — but only at some longitudes, and not at every point in Ceres' orbit. How ice seems to make a patchy, transient water-vapour atmosphere is a new mystery for Dawn to try to solve.



VESTA'S BELT Deep grooves wrap around the asteroid Vesta's circumference, likely created by the reverberation from the impact that excavated the Rheasilvia basin at the south pole.
NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA

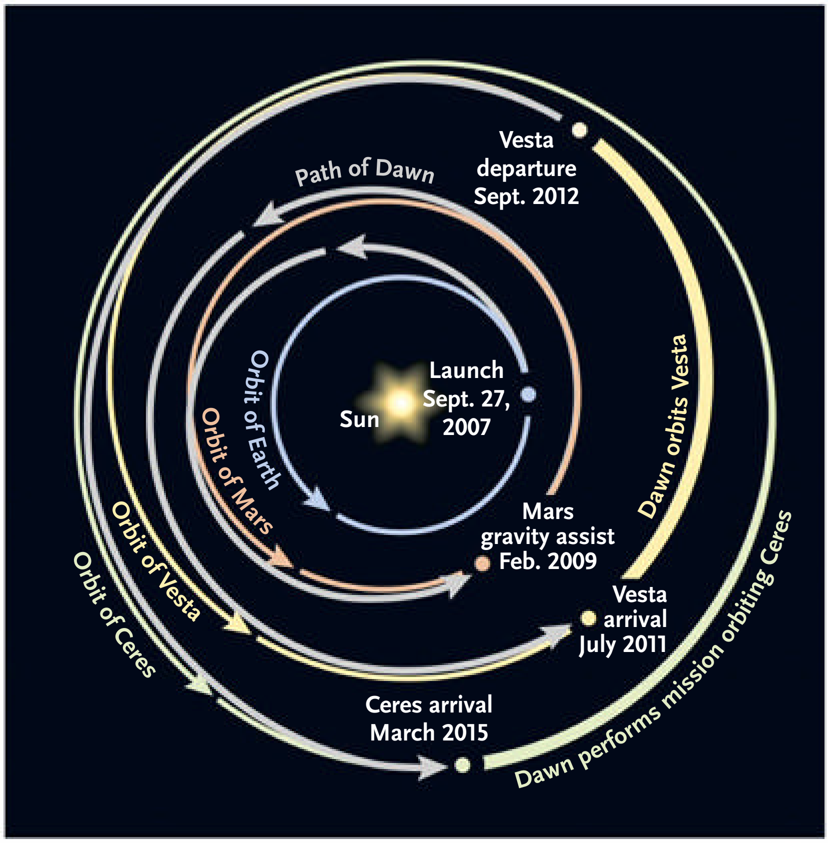
Ceres and Vesta fast facts

Parameter	Ceres	Vesta
Mean Radius (km)	476	263
Mass (kg)	9.39×10^{20}	2.59×10^{20}
Density (kg/m³)	2,075	3,455
Rotation Period (Earth hours)	9.075	5.342
Semimajor Axis (a.u.)	2.76	2.362
Eccentricity	0.079	0.0895
Inclination (degrees)	10.6	7.14
Mean Albedo	0.10	0.40

And there's spectroscopic evidence for water's action on Ceres' surface rocks, in the form of minerals never seen on other asteroids: potentially brucite or another hydroxide, and carbonates. The only other places in the Solar System where we have observed carbonates are Mars and Earth.

A pioneer expedition

Most of the questions driving Dawn's investigation of Ceres are pretty basic, befitting the first reconnaissance of a



DAWN'S INTERPLANETARY VOYAGE **Using ion-propulsion thrusters and a gravity assist from Mars, Dawn travelled nearly four years to reach Vesta, and another 2.5 years to reach Ceres.**
S&T: GREGG DINDERMAN

new world. What covers its surface? How is its interior layered? What is its geologic story? Where and how did it form? Could there ever have been life there?

To answer these questions, Dawn will perform a survey of Ceres almost identical to the one it did at Vesta. With its Framing Camera, it will map all of Ceres in full colour at medium resolution, and all of it in monochrome at higher resolution. It will gather the data to create a global infrared map with its Visible and Infrared Mapping Spectrometer at low resolution, and some locations at higher resolution. It will also photograph the edge of Ceres against the sky to develop detailed shape models. In a three-month low orbit, Dawn will use its Gamma Ray and Neutron Detector (GRAND) spectrometer to map the distribution of different elements, and radio tracking to measure the gravity field.

Dawn's observations of the shape and gravity of Ceres will significantly narrow the range of possible structures for Ceres' interior, which will, in turn, tell us which of the possible stories for Ceres' geologic history are more probable than others.

One of the most intriguing questions that Dawn could answer is: where did Ceres form? Until recently, scientists assumed that most of the objects in the Solar System, particularly the large ones, have been where they are now since their formation. But we now know that giant planets can migrate, and their migrations wreak havoc with the motions of the Solar System's smaller citizens.

Ceres has lots of water, so it can't have formed too close to the Sun. Could it have formed farther away than it is now? Its density overlaps with those of trans-Neptunian objects; researcher Bill McKinnon (Washington University in St. Louis) has gone so far as to suggest that Ceres formed in the Kuiper Belt and was transported to the inner Solar System by the same dynamical process that populated the Trojan points of the giant planets' orbits with icy bodies. Olivier Mousis (now at University of Franche-Comté, France) and Yann Alibert (University of Bern, Switzerland) proposed an intermediate history: perhaps Ceres' rocky centre formed in the asteroid belt, but it accreted an icy envelope later as it caught up smaller Kuiper Belt bodies that drifted into its path. The question of where Ceres formed could be settled with help from GRAND measurements of the ratio of radioactive potassium to thorium. Potassium is more easily evaporated away than thorium, so the ratio between these two elements can change depending on the temperatures an object has experienced in the past — and, therefore, where an object hails from.

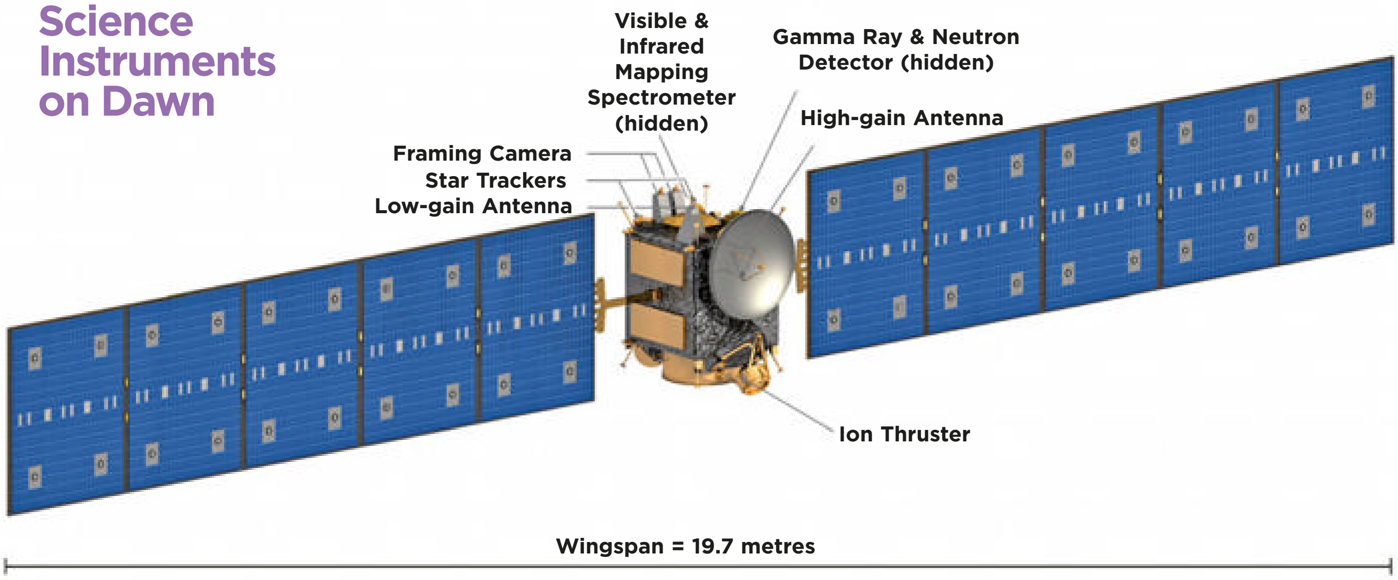
Each of these potential histories could leave its signature in the composition of Ceres' surface and the patterns of its geologic features. For instance, several of the possible stories for Ceres suggest times in its history when it would have needed to change in size. Ice expands as it freezes, and minerals in silicate rocks exposed to liquid water change to other minerals with lower densities than the original ones. If Ceres expanded, we should see *extensional tectonic features* on its surface such as fissures and fractures, possibly even signs of volcanism.

> **"With its Framing Camera, Dawn will map all of Ceres in full colour at medium resolution, and all of it in monochrome at high resolution."**

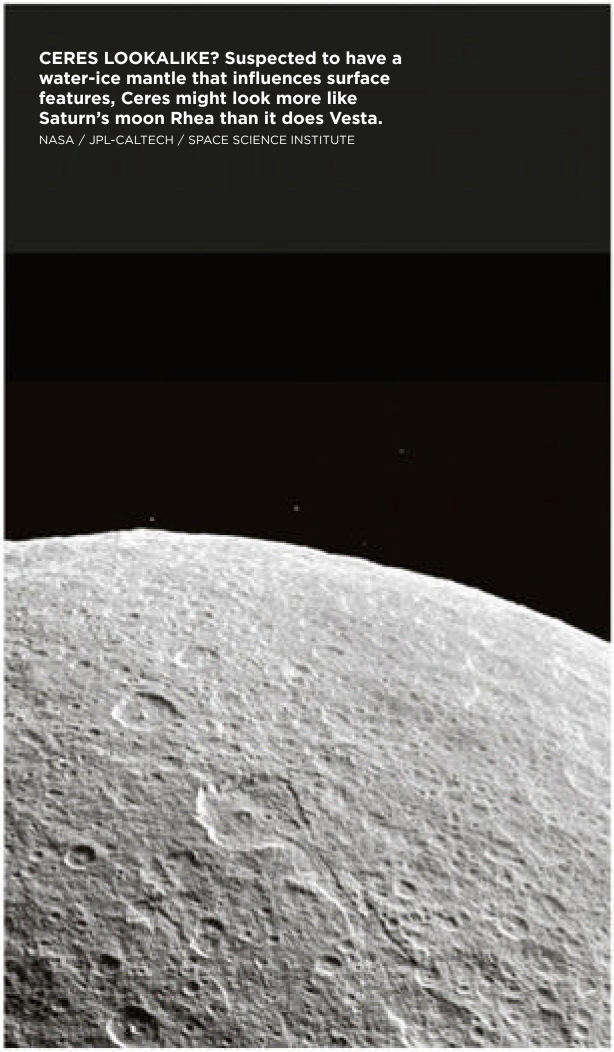
Even if Dawn does not reveal extensional tectonic features, we should be able to detect subsurface ice through the shapes of craters: ice flows over geologic time even if it remains solid, so craters on an ice-rich body should have a relaxed appearance like those on Saturn's moons Tethys or Rhea. If Ceres has features like this, it will be the only place we've ever seen them where the geology wasn't driven by the tidal forces exerted by a neighbouring planetary body. Even Pluto and Charon — to be visited by New Horizons in July this year — will have tectonics that are dominated by the forces that the members of that binary world system exert on each other.

But there's also the possibility that Ceres will keep its secrets hidden.

Science Instruments on Dawn



TRAVELING LIGHT Dawn has a comparatively small, but successful, payload. Its monochrome Framing Camera has seven colour filters and one panchromatic filter to extract as much detail as possible when mapping asteroid surfaces. The Visible and Infrared Mapping Spectrometer detects wavelengths from 250 to 5000 nanometres, covering a wide range of signatures, and its Gamma Ray and Neutron Detector maps elements' distributions across the asteroids' surfaces.
CASEY REED, SOURCE: NASA / JPL-CALTECH / UCLA / MCREL



CERES LOOKALIKE? Suspected to have a water-ice mantle that influences surface features, Ceres might look more like Saturn's moon Rhea than it does Vesta.
NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE

Maybe these changes happened so long ago that they've been obscured by dust and space weathering. Some of the features that Dawn spotted on Vesta that were originally thought to be volcanic — including the splotches and wisps of dark material on the asteroid's surface — are now thought to be organic-rich material brought in later by impacts, completely unrelated to Vesta's internal geology. Whatever processes we see on Vesta, we should also see on Ceres.

What we do know about Ceres is that it is large, it is unmistakably round, and it is brighter in some places than in others. Those three facts make it very likely that Ceres has an exciting story to tell.

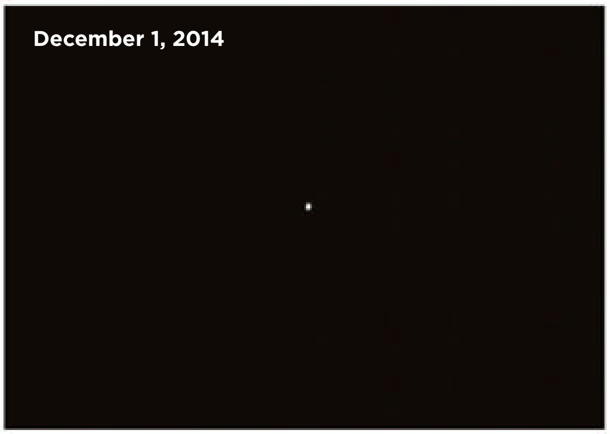
Looping an asteroid

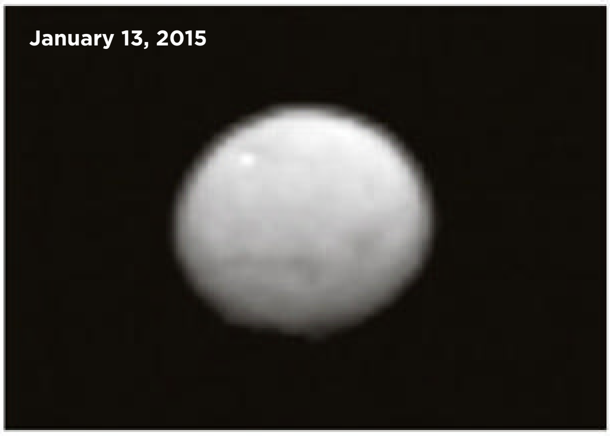
Dawn's science plans for Ceres are very similar to the survey it performed at Vesta, with a few tweaks. Dawn began its approach observations of Ceres in January 2015. The very first images Dawn acquired during approach are similar in quality to Hubble's of this little world, and they will only get better from there.

As Dawn approached, it took nine sets of photos of Ceres while also searching nearby space for possible moons. These included two 'rotation characterisations,' where it watched Ceres through one complete 9-hour Cerean day, imaging the entire globe with both camera and spectrometer in visible and infrared bands.

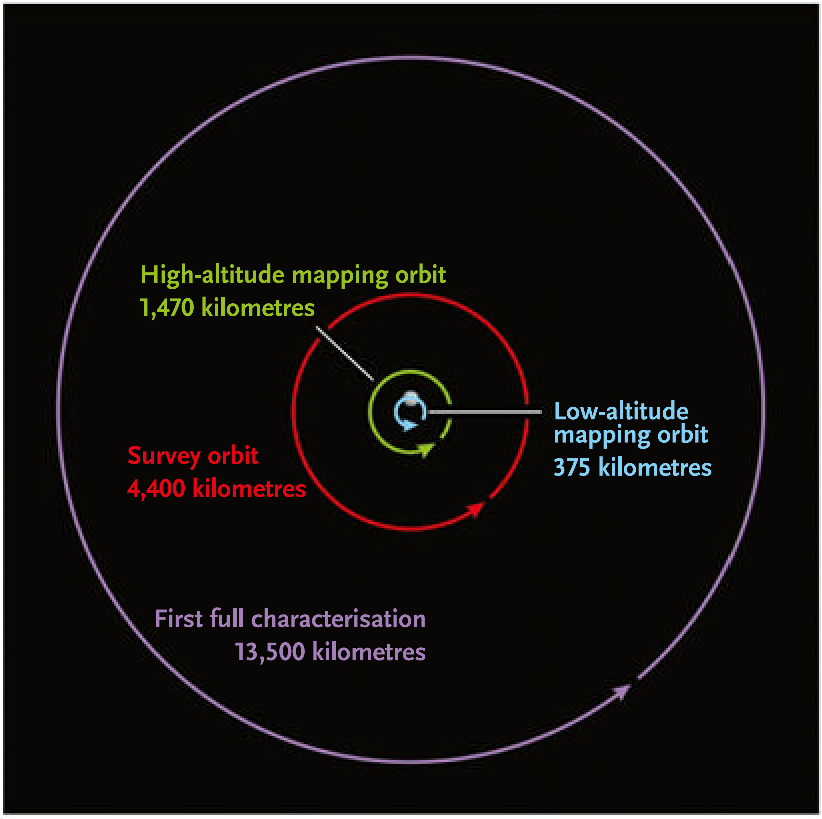
Dawn will arrive in its first science orbit in late April, a polar one at an altitude of 13,500 kilometres, with a leisurely orbital period of 15 days. That's far enough away for Ceres to still fit comfortably within the Framing Camera's field of view, around 700 pixels across. Dawn will watch Ceres rotate through three complete Cerean days, thoroughly characterising its three-dimensional shape. Once its orbit takes it to Ceres' nightside, it will repeat the observation, capturing what will be an exciting set of images of Ceres in a crescent phase.

It will take a month for the gentle pressure of Dawn's ion engines to shift it down to its survey orbit altitude of 4,400 km, where the spacecraft will spend three weeks acquiring global maps with camera and spectrometer. Another six weeks of orbit adjustment will take it to its high-altitude mapping orbit, circling Ceres once every 19 hours at an altitude of 1,470 km. A 12-orbit cycle will carry Dawn over every inch of Ceres' surface. From this high-altitude orbit, Dawn will cover Ceres six times — once looking straight down, and the rest at a variety of angles in order to measure what may be subtle topographic rises and falls.





LAND HO! Ceres was a dot to Dawn's Framing Camera at a distance of three Earth-Moon separations (far left). When the distance closed to match the Moon-Earth system, Dawn saw mottling and a bright spot. DECEMBER: NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA; JANUARY: NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA / PSI



SCIENCE ORBITS Dawn will conduct four different orbits around Ceres, spiraling down from the outermost to the innermost over a few months. SOURCE: NASA \ JPL-CALTECH, S&T: GREGG DINDERMAN

Finally, Dawn will perform its last orbital shift, descending to a low-altitude mapping orbit only 375 kilometres above the surface, about the same as the International Space Station's orbit above Earth. Here, its GRAND spectrometer will be able to most strongly sense the sparse neutrons emanating from Ceres' surface; over time, their energies and locations will tell the Dawn team about the distribution of chemical elements.

While GRAND is mapping the surface, Dawn will also stay in nearly continuous contact with NASA's Deep Space Network. From tiny shifts in Dawn's orbital speed as it circles Ceres, the mission team will be able to map Ceres' gravity field, looking for clues to its internal structure. Dawn will also acquire image data — the highest resolution of the mission — during the lowest orbit, but the focus of this phase is composition and gravity mapping.

In low-altitude mapping orbit, Dawn will prolong its hydrazine supply by switching to a 'hybrid mode' of pointing, where it will use its two remaining functional reaction wheels in combination with hydrazine thrusters to point itself. Hybrid mode will also extend Dawn's life as long as possible. But if, at any point, one of its remaining two reaction wheels fails, it will complete its mapping mission on hydrazine thrusters only.

Regardless of whether the reaction wheels survive until mission's end, Dawn should be left with just a few kilograms of hydrazine propellant when its work in the low-altitude mapping orbit is complete. The orbit is a stable one and the spacecraft will never crash into Ceres. It is possible that NASA will extend Dawn's mission: more time for GRAND in low-altitude orbit will improve its maps, and will fill in gaps in high-resolution imaging.

Had the reaction wheels not failed, Dawn could have finished the Ceres mission with sufficient xenon to depart and travel to a third asteroid destination (although who knows whether it would have). Sadly, that is now out of the question. But there should be no regret. Dawn remains the first spacecraft ever to rendezvous with, orbit, and completely map two alien worlds. And if all goes according to plan, its results will surely be spectacular. ✦

Emily Lakdawalla is senior editor and planetary evangelist for The Planetary Society. She writes about space science and exploration at www.planetary.org. **She thanks Marc Rayman, Carol Raymond, and Andy Rivkin for their assistance with this article.**

WorldWide Telescope

Take a virtual and interactive tour of the universe.

What famous observatory has no lens and no mirror? In centuries past, such primitive institutions could be found worldwide, until the 17th century invention of the telescope revolutionised the meaning of the word "observatory."

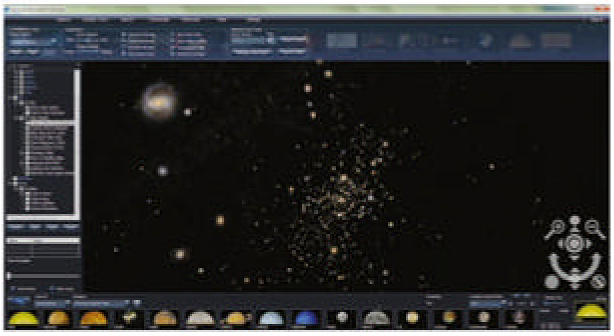
Now the modern age has its own version of an observatory *sans* telescope: the internet. The wealth of online astronomical data grows every day, drawing from spacecraft as well as ground-based observatories around the globe. And there's a portal through which anyone can access these data: the WorldWide Telescope (WWT).

This software runs on web browsers, on Windows as a desktop application, or on other platforms altogether — including planetaria. WWT accesses the amazing online treasure-trove to provide beautiful all-sky imagery at dozens of wavelengths, as well as close-ups of popular celestial targets. Users can find additional information on individual objects by following links to diverse databases, ranging from Wikipedia to NASA's Astrophysics Data System (the repository for most astronomical literature published since the 1800s).

Basically, WWT functions as an interactive web browser for the sky. And best of all, it's free.

A virtual observatory

One of astronomers' first uses of the internet was as a remote-observing tool, enabling them to access telescopes on distant mountaintops and space satellites. Over the decades, data



EXPLORE THE COSMOS Fly through Valles Marineris in the 3D Mars environment ***(left)*** before zooming out to explore stars in the solar neighborhood listed in the Hipparcos catalogue ***(top right)***. Keep scrolling, and soon you'll soar outside the Milky Way, passing through some of the nearly 1 million galaxies drawn from the Sloan Digital Sky Survey ***(bottom right)***. All screenshots are from WWT.

exchange over the web became commonplace, and as detector technologies continued to improve and telescopes became more powerful, the astronomy community realised the potential for creating a set of interconnected data and research tools. The goal: to create the best 'observatory' the world has ever seen.

In 2001 the US National Science Foundation funded the creation of a framework that would evolve into today's US Virtual Astronomical Observatory. Related virtual efforts have appeared in other countries around the world. The effort's backbone is the International Virtual Observatory Alliance (IVOA), an organisation that creates standards for all astronomical data. Though largely invisible to practicing astronomers, the group's work is critical to making data universally accessible. For example, most astronomical images come in a Flexible Image Transport System (FITS) format; IVOA standards put in place a decade ago help astronomers using different types of software search for, view and exchange these images.

ALYSSA GOODMAN

CURTIS WONG

Today, in spite of funding woes in the U.S. and worldwide, the Virtual Observatory has created a set of free astronomical resources that are arguably more coordinated and accessible than in any other field of science. But granting the public access to those resources required a different kind of effort. Enter the WorldWide Telescope.

Building the WorldWide Telescope

Growing up in Los Angeles, amateur astronomer and coauthor Curtis Wong tried to explore the amazing sky presented in magazines. But between city lights and smog, he could only see the Moon, a few planets and some nebulae with his 60-mm refractor. But what he really wanted was a gigantic telescope, a dark sky and maybe even an expert by his side to explain the view.

Years later Wong found himself working at Microsoft Research with big data computer scientist Jim Gray and astronomer Alex Szalay (Johns Hopkins University). Gray and Szalay were producing software to archive, organise and visualise Sloan Digital Sky Survey (SDSS) data. When the pair wrote a seminal paper envisioning 'The World-Wide Telescope, an Archetype for Online Science,' Wong realised that all the elements were in place to bring his childhood dream to life.

Wong presented his ideas at a 2005 astronomy visualisation conference, where he befriended professional astronomer and coauthor Alyssa Goodman. When he finally got the go-ahead to make his project a reality in 2006, Goodman and other astronomers advised him on its content and usability. During the next two years Wong collaborated with software architect Jonathan Fay, an amateur astronomer himself, to build the software; Wong designed the overall experience and Fay developed the code.

After Gray was lost at sea during a 2007 sailing trip, Wong and Fay retitled the project WorldWide Telescope to honour the computer scientist's vision for online astronomy. Launched at a 2008 TED conference, the software was featured in *Sky & Telescope* that same year. Former editor Stuart Goldman explained in an accompanying blog post the best way to explore WWT: "Watch the introductory tours to learn your way around the program — and then left- and right-click on everything!" That's still good advice, even more so now than in 2008.

WWT@HARVARD From left to right, Patricia Udomprasert, director of the WWT Ambassador program, coauthor Alyssa Goodman, astronomer Owen Gingerich, and coauthor Curtis Wong take a moment to explore the universe at a large-screen kiosk in the lobby of the Harvard Science Center. DENNIS DI CICCO

Tour the universe

Today's amateur astronomers are blessed with a wide variety of tools to display the night sky. WWT offers the same functions as other planetarium software, but with unique quality and breadth. The images in the program's database capture the sky in more than 85 different wavelengths — most of these far beyond the spectral window of the human eye.

WWT opens with the night sky as seen from your location. The 1-trillion-pixel view seamlessly stitches together thousands of images from the Digitized Sky Survey, an all-sky photographic atlas. You can zoom in from a 60-degree field of view to a high-resolution close-up of the wisps in the Veil Nebula. You can also look at the same image at two wavelengths, comparing, for example, the Horsehead Nebula in visible-light and infrared images.

Start playing with the controls of the WWT desktop application and a range of options opens up. Simulate eclipses as viewed from Earth or space, or fly to the Moon to view the Lunar Reconnaissance Orbiter's high-resolution images and elevation maps. Travel to Mars and fly through Valles Marineris, or see the distribution of more than 500,000 asteroids tracked by the Minor Planet Center.

Then zoom out from the Solar System and fly through the roughly 118,000 neighbourhood stars drawn from the Hipparcos catalogue. Keep zooming out and you'll pass through nearly one million SDSS galaxies and glimpse the universe's large-scale structure. Right-clicking on any star, planet, or galaxy will reveal deeper information on that object from multiple online sources.

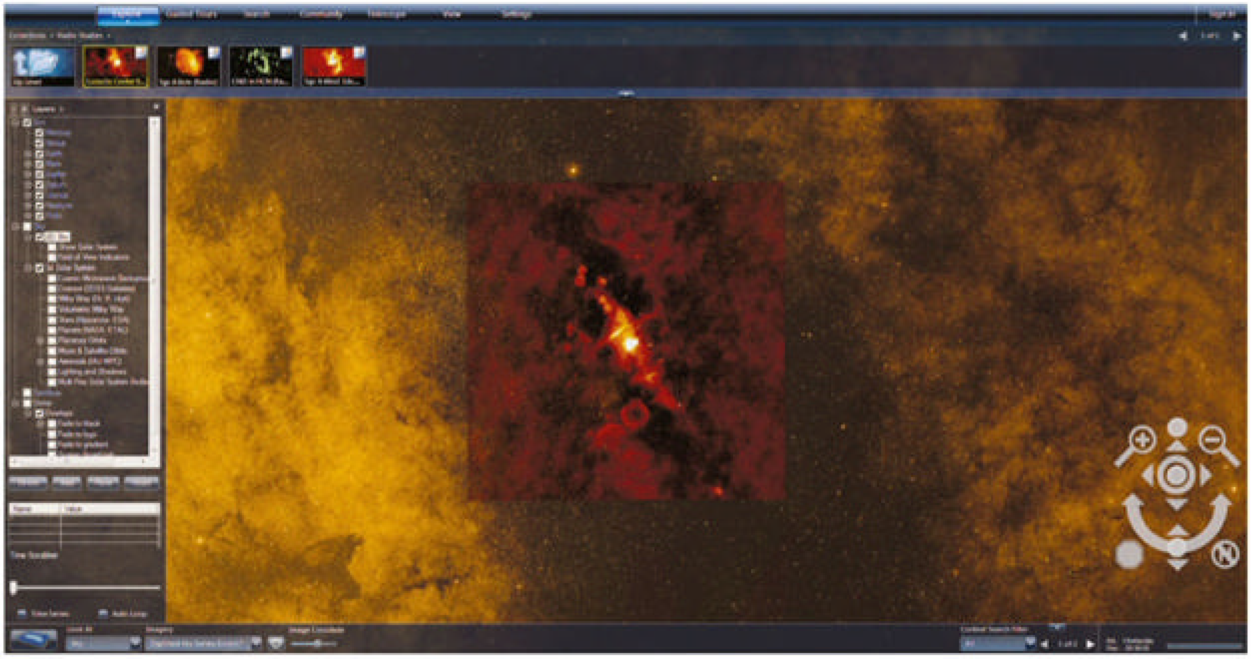
But WWT isn't meant just for solo use. Users of the Windows desktop application can also create and share guided sky tours, saving their path through the program as if a virtual camera were recording the experience. These tours look like videos and can include musical scores, narration, additional imagery and hyperlinks. But unlike with videos, users can interact with the tour as they experience it, exploring a particular topic in detail before picking up right where they left off.

Astronomers and educators have already created dozens of sky tours spanning topics from the very general, such as Astronomy for Everyone, to educational tributes highlighting the work of important astronomers, including *John Huchra's Universe* and *Galileo's New Order.*

The latter tour debuted on the 400th anniversary of Galileo's observations of Jupiter and uses the desktop application's 3D solar system environment to recreate the astronomer's revolutionary observations. The tour juxtaposes the movement of Jupiter's moons, which move back and forth in almost a straight line over time, against Galileo's drawings from *Sidereus nuncius*. To illustrate Galileo's realisation that these observations confirmed the Copernican model of a heliocentric Solar System, the sky tour shows the moons as viewed in the plane of the sky, as well as in three dimensions using modern images from NASA orbiters.

Full functionality, especially of WWT's 3D environments, requires the Windows desktop application, but the browser-based version performs most of the program's basic functions. Some of the interactive tours that rely on the 3D environments are also only

NIGHT SKY WWT opens to show the celestial view from a given time and location, seamlessly stitched together from thousands of Digitized Sky Survey images. Constellation patterns are overlaid by default.



IN DIFFERENT LIGHT WWT enables users to explore images in multiple wavelengths. This view shows our galaxy's centre imaged in 90-cm radio waves overlaid on a visible-light view from the Digitized Sky Survey.

accessible to users of the desktop application, though they are available in video form on the WWT Ambassadors website and on YouTube.

Multiplatform, multidevice, multiscreen

While WWT was initially created as a Windows desktop application, Microsoft Research soon made the software available in a limited, browser-based version accessible from nearly any operating system and device. And as technologies continue to develop, WWT has become available on more than just computer screens.

Find WWT on the big screen at planetariums such as the Adler Planetarium in Chicago and the California Academy of Sciences in San Francisco. Or bring WWT to your backyard, using the software to slew your telescope to celestial targets as you view multiwavelength data on your screen. If you would rather stay inside, plug in an Xbox controller and immerse yourself in 'on-world' experiences such as a rover's view of the Martian surface. With red/blue glasses handy, you can even get the view in 3D.

Perhaps the ultimate experience is to view WWT through Oculus Rift, a headset that plunges you into a virtual reality. (The consumer version of the headset might become available in 2015; so far, only preliminary versions have been released.) WWT offers a virtual tour of the International Space Station (ISS), where you can hover just outside while the Earth rotates below. ISS Commander Chris Hadfield took it for a spin at a 2014 TED conference. His only criticism? The ISS would not have that many Soyuz capsules docked at one time.

Rallying the troops

Multiple studies have shown that students learn more from interactive tools than from traditional learning materials, and kids and adults alike love using WWT — "Cooler than *Call of Duty*," proclaimed one sixth-grade student. So the software makes an ideal platform for astronomy education and public outreach.

To that end, the WWT Ambassadors (WWTA) Program trains active researchers ranging from advanced undergraduates to tenured faculty, as well as retired astronomers. About 100 PhD-level Ambassadors have brought WWT into a wide variety of educational environments over the past few years: creating sky tours, presenting at science fairs and conventions, and aiding in-classroom research. Since kids learn to operate the WorldWide Telescope astonishingly quickly, Ambassadors' primary role is to bring deeper physics, maths, chemistry and engineering knowledge to bear on students' questions. Ambassadors may answer questions online or in classrooms where teachers are using WWTA curricula.

WWT has recruited Ambassadors throughout the U.S. and in countries such as Poland, China and India. If you are interested in bringing WWTA to your area or becoming an Ambassador yourself, we encourage you to contact us via the WWTA website (wwtambassadors.org).

The Ambassador program isn't the only direction WWT is growing. In 2015, WWT's code will become open source. The software is already free to download, but making the code open source means it will also become available to the general public to modify. Those working at universities, high schools, museums or planetaria can go far beyond creating sky tours, changing the code itself to expand and enhance its capabilities, or even incorporating it into their own programs.

WWT's goal has always been to augment professional research while also engaging the general public. Now individuals and institutions with similar goals can leverage WWT to make their mutual ambitions a reality. ✦

Alyssa Goodman, a Harvard University astronomy professor and Smithsonian Institution research associate, and _Curtis Wong_, Principal Researcher at Microsoft Research, have collaborated on the WorldWide Telescope and other astronomy visualisation and education projects for the past 10 years.

Phoenix Planets

The death of a star often has fatal consequences for orbiting planets. But for some worlds, the end of the stellar line could mean a brand-new start.

NOLA
TAYLOR REDD

PULSAR PLANETS **In 1992 astronomers discovered the first exoplanet system, around the pulsar PSR 1257+12. Two of the three planets are a few times Earth's mass; the innermost is slightly less massive than Mercury. Charged particles from the pulsar would probably rain down on the planets, creating auroras (shown on the outermost planet in this artist's impression).**
NASA / JPL-CALTECH / ROBERT HURT (SSC)

We often think of stars and planets as living in lockstep. Most of the known planets in the galaxy formed at the beginning of their suns' lives, grown from clumps in the disks of gas and dust surrounding the young stars. Stars and their planets then eke out billions of years together. Eventually, the death of the star in a planetary system often also spells the end for its planets: a supernova or a swelling red giant can easily demolish close-in planets and affect the orbits of distant ones.

Yet astronomers have discovered some planets orbiting older, evolved stars that do not look like they weathered the stars' deaths. Instead, these exoplanets seem to be much younger. Although few in number, such bodies could potentially make up a class of second-generation planets that formed at the end of their stars' lives, rather than at the beginning.

Arising from the ashes

In 1992, Aleksander Wolszczan (now at Penn State University) and Dale Frail (National Radio Astronomy Observatory, NRAO) discovered the first planets outside the Solar System. To the surprise of many scientists, the two extrasolar bodies didn't orbit a Sun-like star; instead, they orbited a pulsar.

Pulsars are stellar corpses that act as very exact clocks, sweeping their lighthouse-like beams of energy around as they spin with a rate that's so dependable that astronomers can sometimes track it to a precision of twelve decimal places or more. The two planets the team found in orbit around the pulsar PSR 1257+12 created a measurable gravitational drag that affected the pulse, which is what enabled the observers to detect them. A third planet was also soon confirmed.

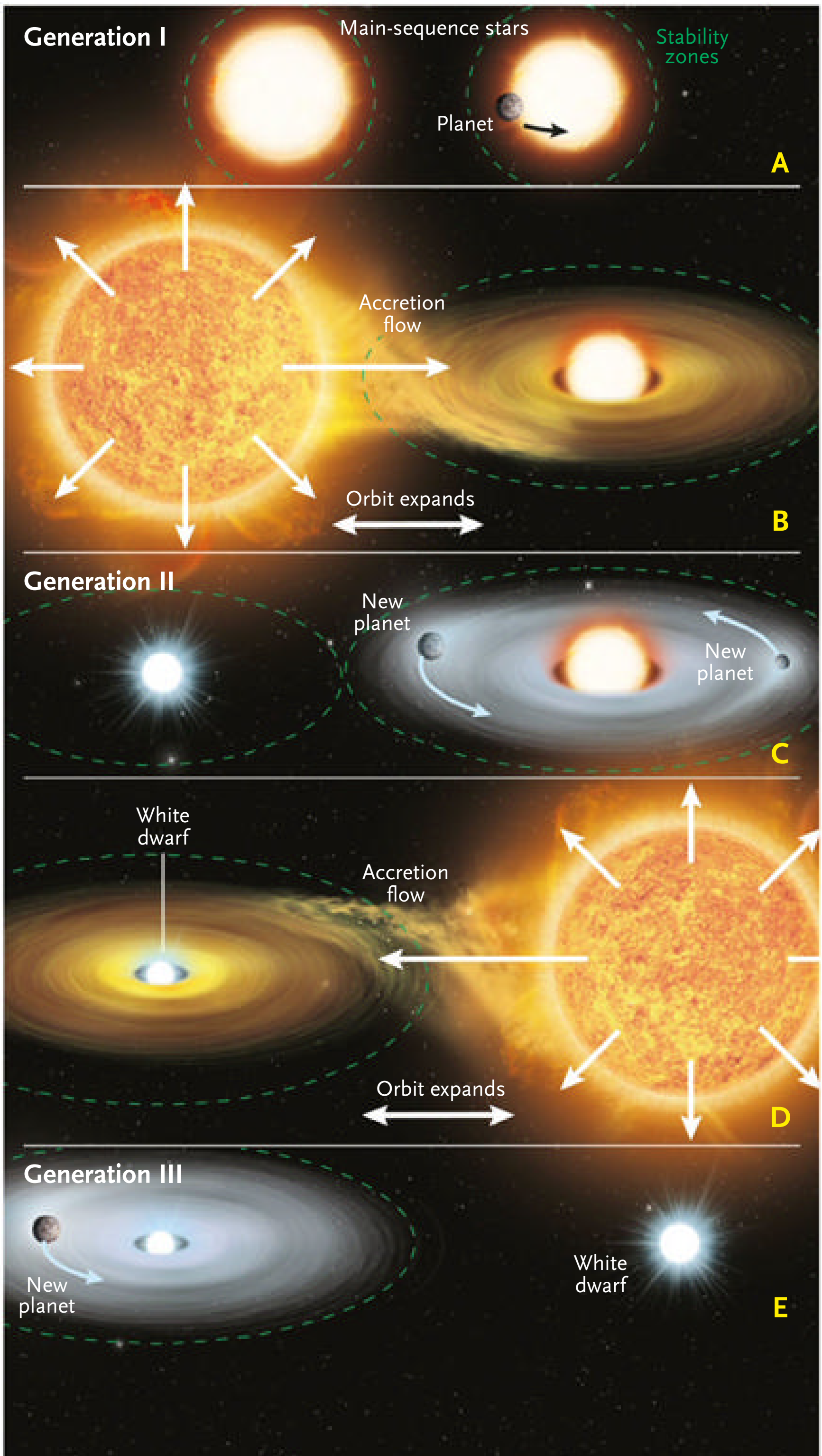
Orbiting at less than half the distance from their star that Earth does from the Sun, these planets could not have survived the supernova explosion that produced the pulsar. Astronomers quickly classified them as second-generation bodies.

After a surge of interest, attention waned when no similar systems were discovered (the next pulsar planet wasn't confirmed for several years). But in 2007, Brad Hansen (UCLA) and Thayne Currie (now at the National Astronomical Observatory of Japan) decided to revisit pulsar planets, applying the information learned about planetary formation over two decades. Their simulation of the PSR 1257+12 system suggested that, after the star's explosive death, some of the debris would not have left the system. Instead, roughly 1,000 solar masses could have remained bound to the pulsar, producing a circling cloud of material with enough solid grains in the innermost section to build the pulsar's three known planets. The planets therefore would have formed from the ashes of the dead star.

Binary mergers and dusty giants

Not all stars explode in violent supernovae at the end of their lives. Stars with masses less than 10 times that of the Sun swell up into red giants. In the Sun's case, the expanding diameter will engulf Mercury and Venus in a few billion years and endanger Earth as well.

If a red giant is part of a binary system whose



HOW PLANET GENERATIONS FORM Planets can form at multiple stages in stars' lives. A planet orbiting a main-sequence star in a binary system occupies a gravitationally stable region (A). When the more massive star in the binary evolves to become a swollen red giant, its outflow can form a disk around the secondary star that is similar to the protoplanetary disk around young stars (B). The mass loss causes the binary's orbit to expand, and planets can form in the accretion disk (C). (The first-generation planet might or might not survive.) When the secondary star evolves, its outflow also engulfs the white dwarf in a disk of material (D). The same orbit expansion and planet formation as in (C) can now happen around the secondary (E). The final giant phase of a star's life lasts a few million years, roughly the lifetime of a first-generation disk.

S&T: GREGG DINDERMAN

companion is very close, it could easily swallow up the second star, shredding it and producing a disk of material with the potential to birth second-generation planets. (Hansen and Currie also explored this idea but found it couldn't explain PSR 1257+12's planets.)

Carl Melis (University of California, San Diego) studies the dusty disks around red giants. He was originally searching for dust disks around main-sequence stars, but in a survey of nearby dust-shrouded objects, he realised that most of the dusty objects he spotted were instead giant stars, a find he deemed "serendipitous."

"No giant star had ever been discovered with copious amounts of dust in its planetary system," Melis says.

Today, Melis has around 20 disk-surrounded stars he is working to confirm are merged binaries, a time-consuming process that requires identifying the amount of gas in the disk. Knowing how much gas is present will allow him to rewind the system to determine if a merger could have formed it.

The material created by a merged binary would bear a strong similarity to the protoplanetary disk that formed early stars, Melis says, with similar conditions in both. But depending on how advanced the swallowed star's core nuclear fusion was, the giant's disk might contain more heavy elements, dredged up from inside the parent star. The levels would not be as high as those in a pulsar's disk, but any increase in heavy elements could affect planet formation: on one hand, gas planets form more readily around metal-rich stars; on the other hand, rapid gas dispersion might keep the disk's mass low, making it difficult to produce gas giants.

"It's hard to say if giant planets would be less likely to form in giant star disks," Melis says. "My gut instinct says that it probably would be harder, but I don't have evidence to support that feeling yet."

Smoking guns

If a red giant is part of a binary system that doesn't merge, it could still form an environment where second-generation planets might bloom. Material blown off the giant star by stellar winds could be trapped in orbit around its companion star, forming a disk similar to those that form young planets. Ultimately, the red giant will lose enough mass to shrink down to a white dwarf, no longer undergoing fusion at its core. But its debris could serve as the building blocks of planets for its still-shining companion star.

One such binary system is Gliese 86. Composed of a white dwarf and a main-sequence star, the system boasts a massive planet closely orbiting the star. According to

Hagai Perets (Israel Institute of Technology), Gliese 86 is a "smoking-gun case" of a second-generation planet.

Before the system evolved, the original binary pair orbited too close to each other to enable a giant planet to evolve and maintain a steady orbit around its host star. But as the massive star blew off its outer layers, the two stars would have drifted apart. If the planet formed from the material flowing off the giant star after the orbit of the binary pair extended, it would explain how the planet safely formed and moved to inhabit the orbit it now does.

A second possibility is that an existing, first-generation rocky planet served as the seed for the gas giant. The rocky planet could have survived the changes in the system, gathering material thrown off by the giant star and becoming a massive gas planet.

Another strong candidate for a second-generation planetary system is PSR B1620–26, a binary system featuring a pulsar and a white dwarf. A planet slightly more massive than Jupiter orbits both stars. The pulsar–white dwarf system is in a globular star cluster, where the low quantity of available heavier elements makes it difficult for planets to form. A second-generation planet, created by the heavy elements from its parent star, provides a more robust solution than the formation of a first-generation world from the element-poor environment. Models that allow the planet to survive the evolution of both stars have been suggested, but require very tight constraints that Perets finds unlikely.

A third system with potential second-generation planets is Epsilon Reticuli, also known as HD 27442. The primary star is an orange subgiant, while the companion is a white dwarf. A Jupiter-mass planet orbits the primary, which is in the process of swelling up to become a red giant. The planet is not a strong second-generation candidate: the distance between the white dwarf and subgiant is roughly 240 astronomical units (a.u.), a bit far for producing an extended, planet-forming or planet-regrowing disk. But the pair is still close enough that HD 27442b cannot be ruled out as a second-generation planet, Perets says.

Binary systems even have the potential to produce third-generation planets. If the companion star in a star–white dwarf system turns into a giant, material flowing from it could produce yet another disk around the white dwarf, potentially spawning an additional generation of planets.

Evolved binary systems make up around 10% of all stellar systems, which would make second- and third-generation planets quite rare. Perets estimates that only a few percent of planets — only 1%, if extremely conservative — exist in such systems. Of the roughly 1,000 confirmed planetary systems, only a handful likely contain these phoenix planets. However, he notes that some planet-finding searches tend to avoid binary systems. The Kepler space observatory's exposure time for transit detections also smear the light curves of short-period binaries, meaning that planet hunters must use inventive analytical techniques to tease out signs of planets.

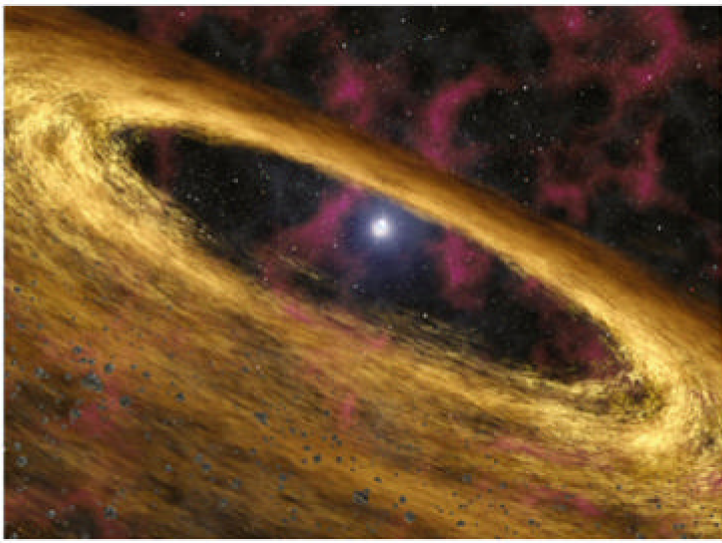
On the fringe

At a time when scientists are scrambling to study and confirm the wealth of new bodies identified by Kepler and other telescopes, second-generation planets remain an object of curiosity. Although few scientists deliberately search for second-generation bodies, that doesn't mean more won't be discovered. Material shed from a star's outer layers has a higher amount of heavy elements than material in a the disks found around a young, forming stars. Not only could that affect the types of planets that form, it could also lead to planets with compositions very different from those of most first-generation planets. As such, if future instruments enable scientists to identify the composition of a planet, second-generation bodies could be identified by more than just their out-of-place orbits.

With pulsars, such detections remain a challenge. After 25 years, PSR 1257+12 remains the only non-binary pulsar confirmed to have planets orbiting it. Part of the reason may have to do with the difficulty in detecting these worlds: if the planets are small and orbit at large distances, their effect on the pulsar may be too small to measure.

Or perhaps pulsar planetary systems are just unusual. "I suspect that it's very rare to even get to the starting point where you have a circumpulsar disk with enough material to form objects," Currie says.

The ideal system, Perets says, would be a binary system separated by 30 to 40 a.u., with one star already evolved to become a white dwarf. The main-sequence star would be about the mass of the Sun, while the white dwarf would have been a few times more massive before it transformed. That mass would ensure the evolving star could dump enough material into orbit around its companion to form planets.



DISKS AROUND DEAD STARS Planet-forming disks could form around old stars much as they do around young ones. This artist's illustration depicts the dust-laden disk around pulsar PSR 4U 0142+61, detected by NASA's Spitzer Space Telescope. Planets might form in this 'fallback disk,' which surrounds a star that went supernova roughly 100,000 years ago. NASA / JPL-CALTECH

Given these caveats, finding second-generation planets might seem like searching for the proverbial needle in a haystack. But if found, these worlds could help scientists to understand more about how first-generation planets form, too. As Hansen and Currie studied PSR 1257+12, they realised that if the planet-forming material were confined in regions known as 'planet traps,' it could produce the system astronomers had observed. Such traps could also explain the layouts of other planetary systems.

And so even though they're peculiar and hard to find, phoenix planets might provide interesting targets in the ongoing search for planets beyond the Solar System. As the rising numbers of exoplanets continue to amaze us with their variety, these planets demonstrate that even a dying star could give birth to an alien world. ✦

Freelance science writer *Nola Taylor Redd* loves to write about all things astronomical.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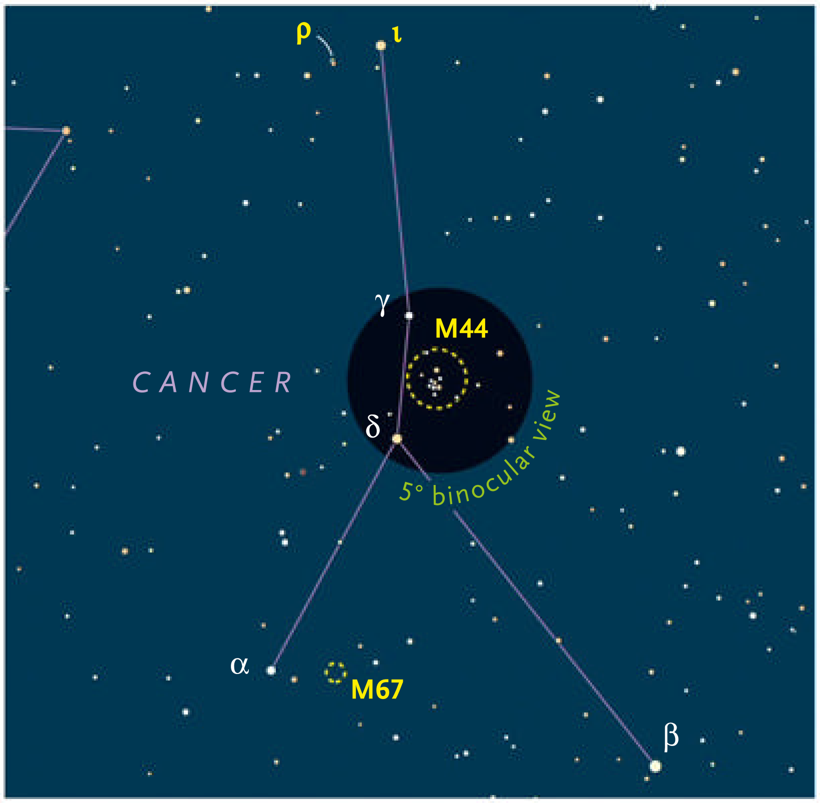


Treats in Cancer

For such a small and indistinct constellation, Cancer has more than its share of binocular treats. The Crab can lay claim to two nice open clusters and a couple of good double stars.

Let's start with the constellation's finest object, **M44** – also known as the Beehive Cluster. One of the very best binocular clusters, M44 features a couple dozen stars sprinkled over an area as wide as two full Moons. Through 10×50s, it's a lovely sight, and a rival to the Pleiades. Whenever I look at M44, my eye is drawn to a miniature version of the constellation Corvus near the cluster's centre. Do you see it?

Two binocular fields south-southeast of the Beehive lies the constellation's other binocular cluster, **M67**. Although it lacks the grandeur of its neighbour, M67 is an easy find. My 10×50s show it as a slightly grainy, elongated patch of light with a 7.9-magnitude star marking its northeast extremity.

Northern Cancer has two fine binocular double stars, **Iota** (ι) and **Rho** (ρ) **Cancri**. Rho is the easier of the two, as both component stars are bright (magnitude 5.9 and 6.3) and are separated by a generous 278 arcseconds. Interestingly, the northern star of the pair (also known as 55 Cancri) was one of the first discovered to have an exoplanet. Compared with Rho, nearby Iota is a challenging target. I find it a difficult split with tripod-mounted 10×50s because the primary is 10 times brighter than the secondary (magnitudes 4.0 and 6.5, respectively). To make matters worse, the stars are separated by only 30 arcseconds. I would wager splitting Iota is all but impossible with 7× binoculars. ✦

USING THE STAR CHART

WHEN

Late April	11pm
Early May	10pm
Late May	9pm
Early June	8pm
Late June	7pm

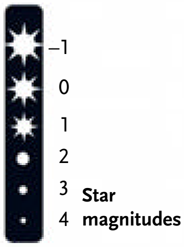
These are standard times.

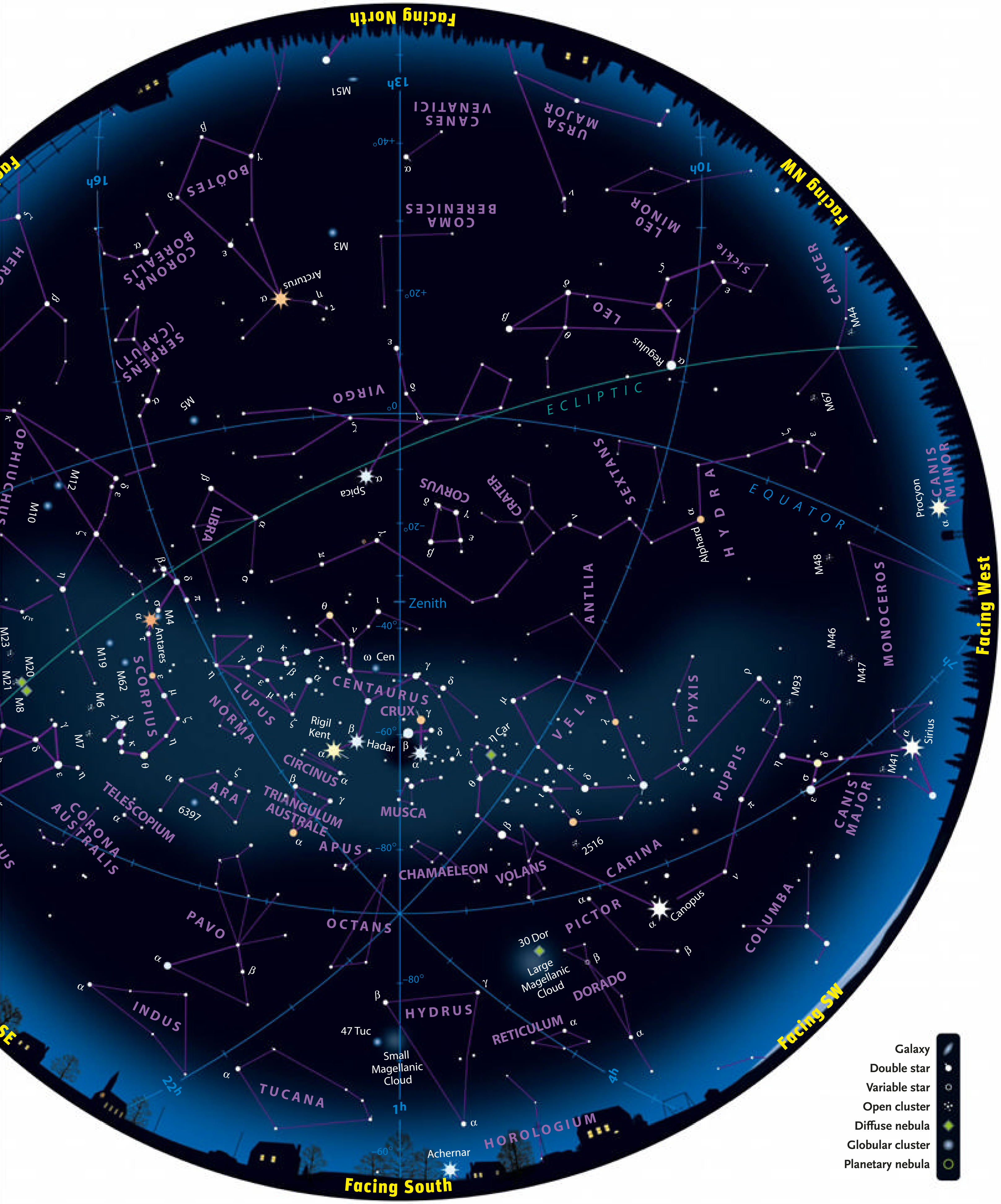
HOW
Go outside within an hour or so of a time listed above. Hold the map out in front of you and turn it around so the label for the direction you're facing (such as west or northeast) is right-side up. The curved edge represents the horizon, and the stars above it on the map now match the stars in front of you in the sky. The centre of the map is the zenith, the point in the sky directly overhead.

FOR EXAMPLE: Turn the map so the label "Facing SW" is right-side up. About a third of the way from there to the map's centre is the brilliant star Canopus. Go out and look southwest nearly a third of the way from horizontal to straight up. There's Canopus!

NOTE: The map is plotted for 35° south latitude (for example, Sydney, Buenos Aires, Cape Town). If you're far north of there, stars in the northern part of the sky will be higher and stars in the south lower. Far south of 35° the reverse is true.

ONLINE
You can get a sky chart customised for your location at SkyandTelescope.com/skychart




Facing North
Facing NW
Facing West
Facing SW
Facing South
Zenith
ECLIPTIC
EQUATOR
URSA MAJOR
CANES VENATICI
COMA BERENICES
BOÖTES
CORONA BOREALIS
SERPENS (CAPUT)
VIRGO
LEO MINOR
LEO
Sickle
Regulus
CANCER
Arcturus
Spica
CORVUS
CRATER
SEXTANS
HYDRA
Alphard
Procyon
CANIS MINOR
MONOCEROS
LIBRA
ANTLIA
Antares
SCORPIUS
OPHIUCHUS
CENTAURUS
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CIRCINUS
η Car
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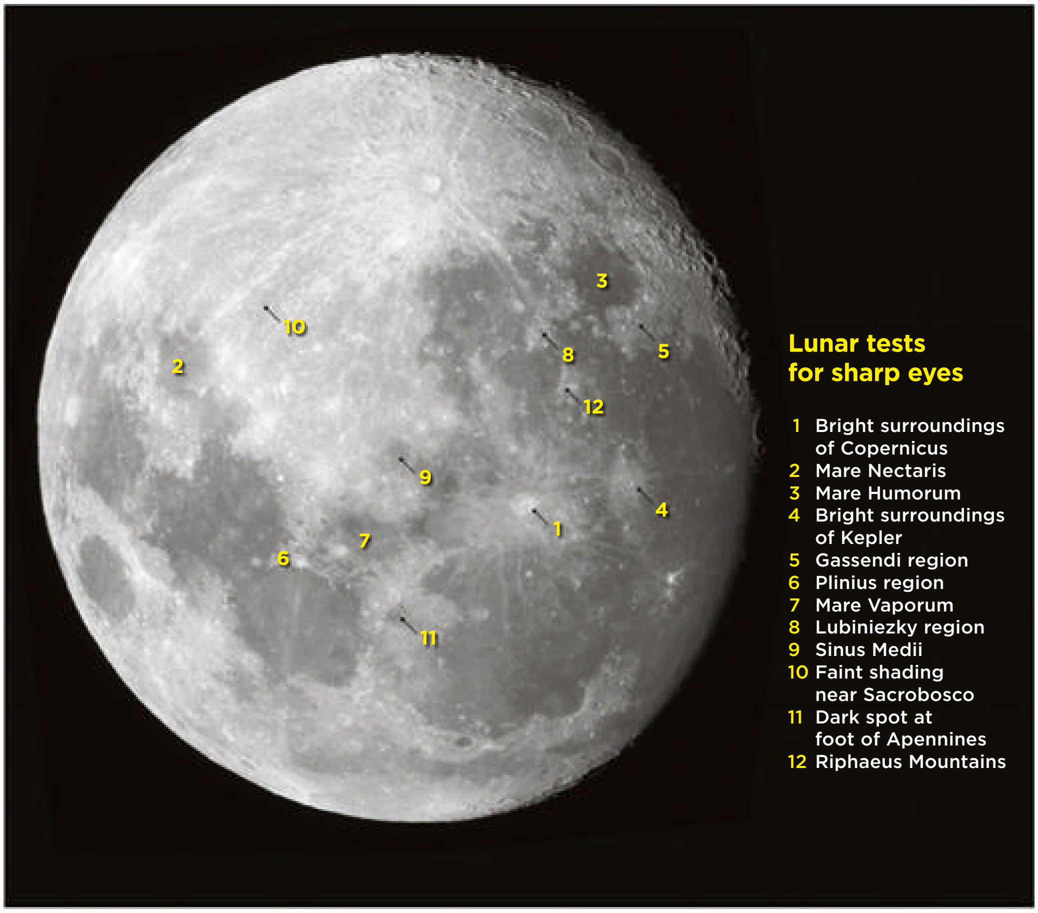
PYXIS
PUPPIS
CANIS MAJOR
Sirius
ARA
TRIANGULUM AUSTRALE
MUSCA
APUS
TELESCOPIUM
CORONA AUSTRALIS
CHAMAELEON
VOLANS
CARINA
2516
Canopus
PICTOR
COLUMBA
OCTANS
PAVO
30 Dor
Large Magellanic Cloud
DORADO
INDUS
HYDRUS
RETICULUM
47 Tuc
Small Magellanic Cloud
TUCANA
HOROLOGIUM
Achernar
M51
M3
M5
M12
M10
M4
M19
M62
M6
M7
M20
M21
M8
M23
M44
M67
M48
M46
M47
M93
M41
6397
13h
10h
16h
22h
1h
4h
+40°
+20°
0°
−20°
−40°
−60°
−80°
Galaxy
Double star
Variable star
Open cluster
Diffuse nebula
Globular cluster
Planetary nebula

A close look at the Moon

What's the smallest detail you can see on our lunar cousin?



S&T: GARY SERONIK

Newcomers to astronomy are often surprised to learn that they can see more on the Moon with the naked eye than they'll be able to see on the planets with a large telescope. But it's true. The naked-eye Moon is a rich target.

So it's remarkable that pre-telescopic astronomers took almost no interest in what they could see right in front of them on moonlit nights.

After all, Aristotle had said that heavenly bodies were perfect crystalline spheres. That pretty much settled the matter for Western philosophy and religion for the next 1,900 years, until Galileo. The Moon's grey spots and finely detailed white markings had to be some insignificant illusion — Earthly atmospheric effects, perhaps, or maybe reflections of the Earth's own lands and seas. Nothing worth paying attention to, anyway.

A few dissenting voices are known from those 1,900 years. In 1st-century Rome, Plutarch easily refuted the notions that the atmosphere or reflections were at fault. He then reasoned out that the Moon was like another Earth. It reflected sunlight as a rough surface would, whereas a polished crystal ball would show a small, bright specular reflection of the Sun. He correctly attributed slight irregularities on the Moon's terminator to mountains casting long shadows. As an analogy, he described how Mount Athos in northern Greece casts a shadow near sunset that extends 80 kilometres across the Aegean Sea to the island of Lemnos. Plutarch may have observed the shadow of the lunar Apennines, the 19th-century lunar astronomer J. H. Mädler suggested. The Apennines briefly produce a definite naked-eye irregularity in the terminator around first and last quarter.

Then in the 11th century, the Arab astronomer al-Haitham, better known as Alhazen, argued that because the Moon's markings never changed shape, position, or size, they were permanent areas of different materials. He wrote that the darker ones should be denser rock. But Plutarch and Alhazen were almost completely ignored despite their renown for their other writings. Not until the century before Galileo did the idea of the Moon having actual blemishes start gaining traction.

Meanwhile, anyone with eyes could see that the Man in the Moon never changed, regardless of the weather or the Moon's position in the sky.

What's the smallest lunar feature you can see with the naked eye? Look carefully, and you may be amazed.

About a century ago William H. Pickering, the brother of Harvard Observatory director Edward C. Pickering, drew up a list of 12 test features in order of increasing difficulty. They're marked on the photo.

The waxing gibbous Moon early in evening twilight presents a favourable opportunity for viewing, though the air then is less often crystal clear.

It also matters whether the Moon is near perigee or apogee. The size difference between a 'supermoon' and a 'mini-moon,' as they've recently come to be called, is not obvious to the naked eye. But for detecting limit-of-vision details, I've found that features that are normally borderline definitely become easier around perigee.

What else in our everyday lives, we may wonder, has gone unnoticed for centuries because we assume there's no reason to look at it critically?✦

The Venus and Jupiter show

The two brightest planets join forces in June

Well the nights are getting longer, and colder, the summer constellations are waning and the winter constellations are settling in to take their turn in the night sky. The Milky Way now spans the sky from eastern to western horizon, and the Southern Cross is up nice and high in the south. It's a great time for stargazing.

Our first planet is **Mercury**, which begins May low in the western sky after sunset. Although it will reach its maximum angular separation from the Sun of 21 degrees on May 7, the angle of the ecliptic means that the innermost planet will only be six degrees above the theoretical horizon. So you'll need to have a clear horizon and look hard to see it.

But not to worry — Mercury will soon reappear in the eastern pre-dawn sky, rising higher as June progresses and reaching a maximum angular separation from the Sun of 22 degrees on the 25th. Watch for the Moon nearby on the 15th, and also for Mercury's close encounter with the Hyades star cluster and the star Aldebaran on the 23rd and 24th.

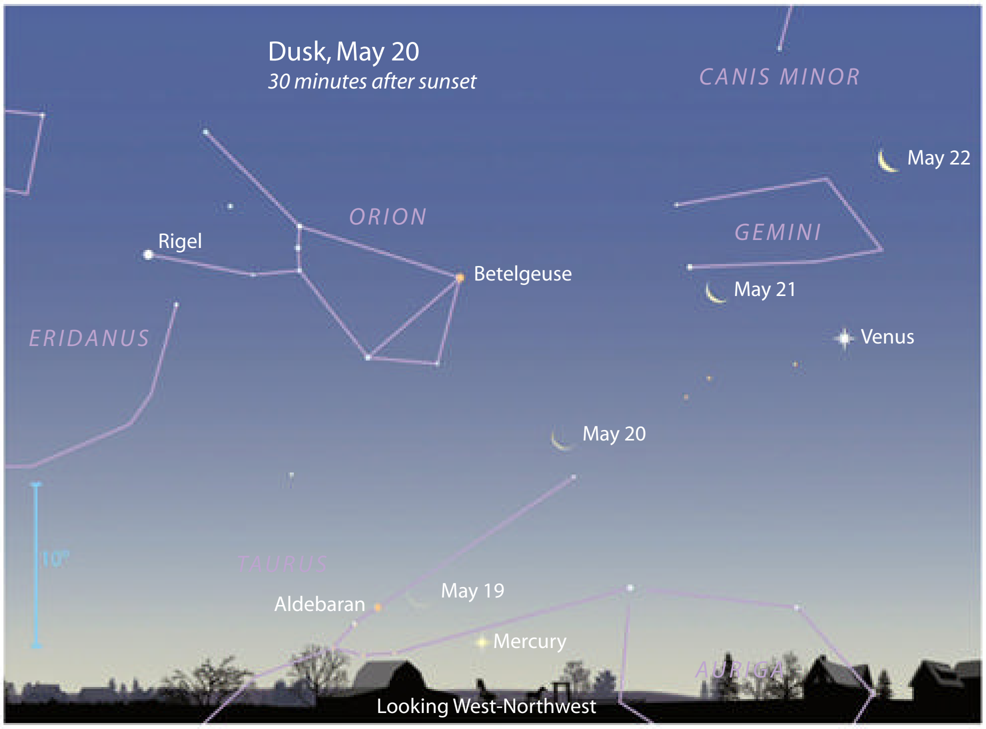
The brilliant **Venus** is shining brightly in the western sky at sunset. Take a look on June 14 and you'll find it near the star cluster M44, also known as the Beehive cluster. And pay particular attention to towards month's end, as Venus and Jupiter slide closer together, culminating with them less than one degree apart on July 1.

Mars, unfortunately, is too close to the Sun to be seen. The Red Planet will reach conjunction on June 15, and won't reappear in our skies until August, when it will become a morning object.

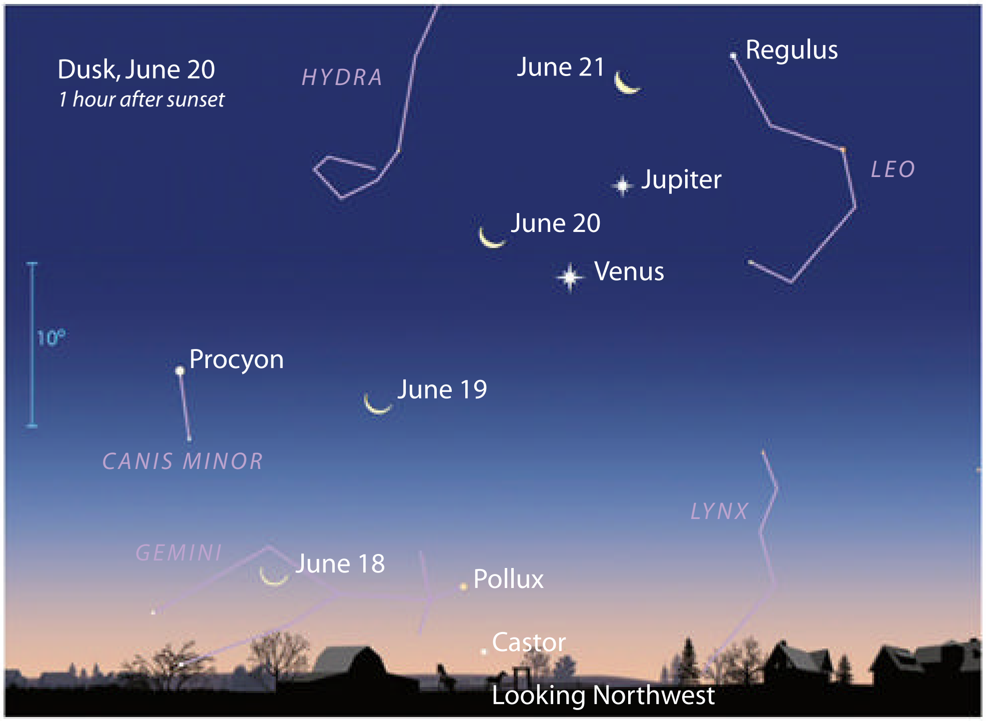
Jupiter, the king of the planets, is prominent in the north-western sky after sunset. Watch for the Moon nearby on May 24, and then get ready for the planet's duet with Venus in June, as described earlier.

Saturn is very well placed for viewing, reaching opposition on May 23. This means it will be rising in the east soon after the Sun goes down in the west, making the planet visible all night long. Look for the Moon just to its left on May 5 and June 1.

In our next issue, we'll provide observing tips for finding **Pluto**… timed nicely to coincide with the fly-by of NASA's New Horizons spacecraft. Pluto is far too faint to be seen with the naked eye, binoculars or small telescopes, but if you have a large backyard and scope and are fairly good at identifying star fields, you should be okay.



You'll have to be quick and have sharp eyes to spot Mercury on May 19, before it slips below the north-western horizon.



Venus, Jupiter and the crescent Moon will form a delightful trio in late June. On July 1, Venus and Jupiter will appear less than one degree apart.

Events Of Note

May	**2**	Spica 3º south of the Moon
	4	Full Moon
	6	Saturn 2º south of the Moon
	11	Last quarter Moon
	12	Mercury 8º north of Aldebaran
	18	New Moon
	22	Venus 8º north of the Moon
	23	Saturn at opposition
	24	Jupiter 5º north of the Moon
	25	Regulus 4º north of the Moon
	25/26	First quarter Moon
	30	Spica 4º south of the Moon
June	**2**	Saturn 2º south of the Moon
	2	Antares 9º south of the Moon
	2/3	Full Moon
	9/10	Last quarter Moon
	16/17	New Moon
	20	Venus 6º north of the Moon
	21	Jupiter 5º north of the Moon
	22	Winter solstice
	22	Regulus 4º north of the Moon
	24	First quarter Moon
	26	Spica 4º south of the Moon
	29	Saturn 2º south of the Moon

Times are listed in Eastern Australia Standard Time

Moon, May 2015

Phases

Full Moon	May 4, 03:42 UT
Last Quarter	May 11, 10:36 UT
New Moon	May 18, 04:13 UT
First Quarter	May 25, 17:19 UT

Distances

Perigee 366,024 km	May 15, 00h UT
Apogee 404,244 km	May 26, 22h UT

June 2015

Phases

Full Moon	June 2, 16:19 UT
Last Quarter	June 9, 15:42 UT
New Moon	June 16, 14:05 UT
First Quarter	June 24, 11:03 UT

Distances

Perigee 369,711 km	June 10, 05h UT
Apogee 404,132 km	June 23, 17h UT

Jamie Cooper took this shot of a bright white Venus and a ruddy Mars being spied upon by the Moon on February 22.

Stargazers were treated to the Aurora Australis at lower than normal latitudes on March 17/18. Russell Cockman took this shot overlooking Port Philip Bay in Melbourne on the morning of the 18th.

Comet Howell in the pre-dawn sky

David Seargent

A good target for observers with large binoculars

As we saw last month, the short-period comet 88P/Howell returned on April 6 and, if it follows the pattern of earlier returns, should become bright enough for large binoculars as it drifts across the pre-dawn sky.

Early May finds the comet in Aquarius, briefly visiting Pisces around the middle of the month before crossing into Cetus from the last week of that month until the second week of June, when it once more crosses the boundary into Pisces. It will already be fading slightly from its extended April peak, but will likely be around magnitude 10.5 as May begins, slowly dimming to 11 or thereabouts by the end of June. As we remarked last month, it will not be spectacular, but at least will give early-risers armed with large binoculars or small telescopes an extended period of visibility.

A far more distant visitor will also drift through the same part of the sky — near the Aquarius/Pisces boundary — during May and June and, although there is no specific reason to think that it will become bright enough for small telescopes, there is just a possibility that it might spring a surprise.

The object in question is the Centaur/comet 174P/Echeclus. This remote object reached perihelion on April 22 at a distance of 5.8 a.u. Normally, it is inactive and asteroidal in appearance and is unlikely to be brighter than magnitude 17 during the period in question. But during December of 2005, it suddenly developed a cometary coma and brightened by several magnitudes. On December 30 of that year, astronomers found that a small and, presumably, temporary fragment had broken away from the main body and that it was this secondary rather than the principal that was the centre of activity. After a while the secondary disappeared and Echeclus settled down once more to its asteroidal appearance.

Then, in June 2011 it flared again, developing a new coma that on this occasion seemed to be centred on the main object. No secondary fragment was noted in 2011, although it is possible that the new centre of activity was the 'scar' left by the schism six years earlier. The 2011 outburst was not as major as the earlier one and by July of that year the coma was already dispersing and fading away.

The position of 174P in its orbit apparently bears no relation to the outbursts, so there is no real reason to expect that it will flare again during its perihelion year. However, if it does happen to outburst with the severity of its 2005 display, because it is now so much closer to Earth and Sun, it could reach ninth magnitude, so a sweep over its position after observing 88P may (just possibly) bring a surprise!

During the second half of June, the dynamically new comet C/2013 US10 (Catalina) may become visible through small backyard telescopes as it approaches its November 15 perihelion at 0.82 a.u. from the Sun. Located in Sculptor during the second half of this month, the comet drifts slowly southward and should brighten by about one magnitude to around 10 by the end of June.

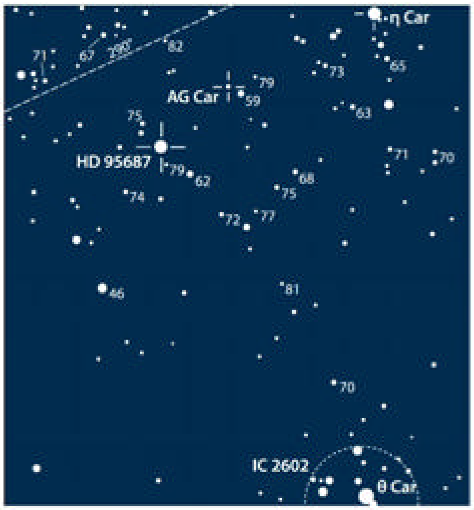
Discovered with the 68-cm Schmidt-Cassegrain telescope during the on-going Catalina Sky Survey on October 31, 2013, as a faint object of essentially asteroidal appearance, Catalina is expected to brighten considerably later this year, although it will be poorly placed around the time of perihelion. Nevertheless, it may become visible through small binoculars in coming months... but more about this in future issues! ✦

David Seargent's **ebook,** ***Sungrazing Comets: Snowballs in the Furnace,*** **is available from Amazon. Extra info on sungrazers can be found on his web site at david-seargent.simplesite.com**

A red super-giant in Carina

Alan Plummer

A variable star similar to Betelgeuse



This column has looked at several variable stars in the constellation Carina: Eta Car itself, then AG, HR, BO, IX and so on. These variables are all close in the sky to NGC 3372, the Eta Carina Nebula. No other area in the sky has given us so many bright targets. Why?

Take a look at the chart. Notice the galactic equator? This is where our galaxy's gas and dust is concentrated, and most new stars originate. But the galactic equator goes right around the sky, so that's not the answer.

Notice next the galactic longitude of 290 degrees, marked. A look at a map of the Milky Way shows that that longitude points right down the length of the Milky Way's Carina Spiral Arm. So, unique in all the sky, this small area looks down the length of a spiral arm. The variables here are all very luminous stars, visible through light-years of gas and dust.

This months target is no exception. HD 95687 is a red super-giant very similar in spectrum and variability to Betelgeuse. The chart shows its location, and comparison stars with magnitudes marked (and decimal points omitted to avoid confusion with faint stars). It's best to observe it once every 7 to 10 days, and, as always, you're encouraged to lodge your observations with the AAVSO (American Association of Variable Star Observers). Believe it or not, you may be the only one looking! ✦

Alan Plummer **observes from the Blue Mountains west of Sydney, and can be contacted on alan.plummer@variablestarssouth.org**

Jovian satellite peek-a-boo

Steve Kerr

Watch as Io casts its shadow onto Europa

Over the years, we've covered a range of occultation phenomena — mostly where the Moon occults a bright star or planet, or in some cases, where an asteroid occults a distant star as seen from a narrow strip on Earth. This month, we're going to look at something different altogether. In fact, it is not technically an occultation at all. Instead, this month we feature a mutual eclipse between two of the major satellites of Jupiter.

The four major Galilean satellites of Jupiter — Io, Europa, Ganymede and Callisto — would be straightforward to see with binoculars if not for the fact that Jupiter itself drowns them with glare for much of the time. They orbit Jupiter in periods ranging from just over 3.5 days for Io through to over 16 days for Callisto, and all of their orbits are tightly bound to the equatorial plane of Jupiter.

With Jupiter's rotation axis tipped only slightly more than three degrees with respect to its orbit around the Sun, Io, Europa and Ganymede pass through Jupiter's shadow on each and every orbit, with Callisto also participating in these eclipses around the time of the Jovian equinoxes. These disappearances and reappearances are quite spectacular for visual observers — timing them with my little 50-mm refractor back in the 1980s was one of the first observing projects I participated in.

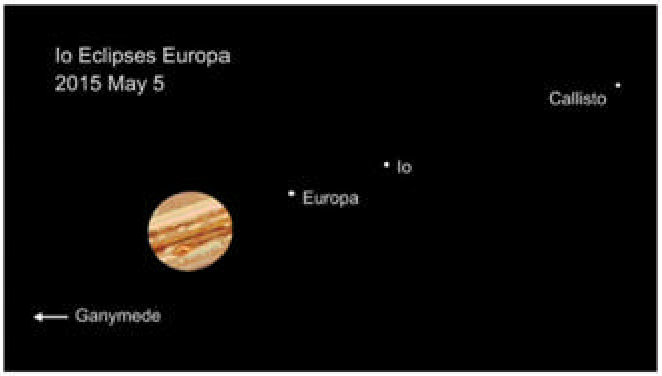
But something else happens around the time of Jupiter's equinoxes — that time when the equatorial plane of Jupiter and its satellite's orbits line up with the Sun and Earth. The satellites start to occult each other as seen from Earth, with the current round of events occurring between August 2014 and late August 2015. (Jupiter's equatorial plane pointed towards the Sun — hence its equinox — back on February 4, 2015.)

For visual observers, the occultations simply make it seem like the satellites are merging and then separating. Those using video equipment and careful image analysis can detect the dimming as one satellite obscures the other, but they are not the most spectacular event to behold. However, advanced amateurs accomplished in high-resolution planetary imaging of the kind that can show these satellites as tiny disks, may be able to produce some interesting images of overlapping disks.

During the August 2014 to August 2015 period, the Jovian satellites can be seen to eclipse each other, where one satellite casts its shadow on another one. The two satellites will in fact be some way apart in the sky at the time. Many of these eclipses are quite shallow (the eclipsed satellite only fades slightly), but one of the more spectacular events will occur early in the evening of May 5.

On this occasion, Io will cast its shadow onto Europa while both satellites are to the west of Jupiter. While Io is larger than Europa, the distance between them will mean that the umbra of Io's shadow will be smaller than Europa, and thus will not cover it completely. So what will be seen is that a dark circle will cross the northern half of Europa while the rest of it will be dimmed by Io's penumbra, but still visible. Overall, Europa can be expected to dim by around 1.3 magnitudes, so observers with even moderate-sized telescopes should be able to comfortably see Europa throughout the event. This will probably be the 'deepest' eclipse associated with the current Jovian equinox.

When do you need to look? Well,



The shadow of Jupiter's moon, Io, will fall on Europa in the early evening of May 5, 2015.

unlike occultations where the timing varies for different observer locations, this is a case where everyone will see the same thing at the same time. (However, observers in Western Australia and much of the Northern Territory and western South Australia will still have the Sun above the horizon, which will make locating Jupiter difficult without a Goto mount, and seeing the satellites will be challenging without larger apertures.) The table shows the times of the start, mid and end points of the eclipse for each of the time zones across Australia and New Zealand. The diagram (using Guide 9 planetarium software) shows the positions of the satellites at the time of eclipse.

There are many ways to enjoy this event. You could just sit back and watch Europa dim and recover over the three minutes. Or you could try your hand at imaging the stages or even building a time-lapse video sequence of the event. And as shown in the diagram, the Great Red Spot will be coming up to transit Jupiter's disk less than an hour later, which will add to the visual appeal. There is some science to do be done too. Paris Observatory is collecting carefully made observations by amateurs of this and the other mutual occultations and eclipses as part of a program of ongoing refinement of the orbits of the satellites. Full details are at www.imcce.fr/en/observateur/campagnes_obs/phemu15/ ✦

Io eclipses Europa – May 5, 2015

Event	New Zealand Standard Time	E. Australian Standard Time	C. Australian Standard Time	W. Australian Standard Time
Penumbra first contact	20:13:33	18:13:33	17:43:22	16:13:33
Umbra first contact	20:14:40	18:14:40	17:44:40	16:14:40
Mid eclipse	20:16:12	18:16:12	17:46:12	16:16:12
Umbra last contact	20:17:40	18:17:40	17:47:40	16:17:40
Penumbra last Contact	20:18:30	18:18:30	17:18:30	16:18:30

***Steve Kerr* is a Queensland-based amateur astronomer and active occultation observer.**

Virgo's double star varieties

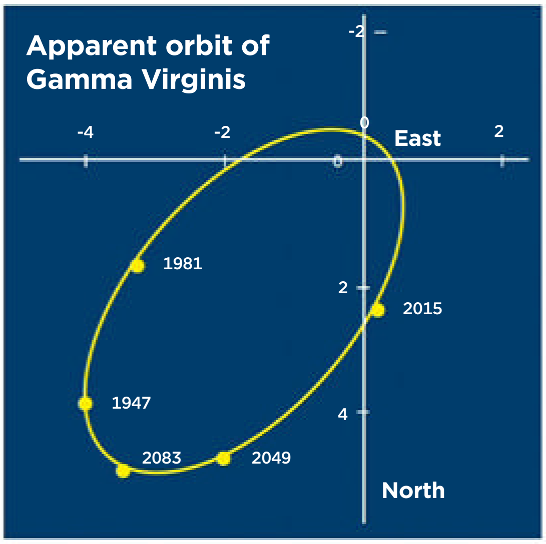
This giant constellation holds many sights for small scopes

This month's doubles are in the region of the showpiece **Gamma Virginis (STF 1670)**. It's a nearby system, 38 light-years from us; the very elliptical orbit takes the pair from a near approach of 5 a.u. (the distance of Jupiter from the Sun) to 81 a.u. (about twice the average distance of Pluto from the Sun). The orbital period is 169-years, and in 2005 the nearly identical stars were at their closest approach, about 0.3" apart, a repeat of 1836 when John Herschel had recorded the pair as briefly becoming single through his 47-cm reflector. He had calculated an orbit for the pair in 1833, making it only the second binary star orbit to be determined.

Sissy Haas, in her book *Double Stars for Small Telescopes*, noted that with a 60-mm telescope the stars of Gamma Virginis were *"easily apart in 1985, a figure-8 in 1995, and a single star in 2000"*. Larger scopes could follow the closing pair for a number of years after that; they've gradually widened since 2005. With my 140-mm refractor, in 2009 the stars were barely separated at 200x (1.3"); the same telescope in 2014 separated at 100x (2.2"). Gamma is now again visibly double with 60- to 80-mm scopes, and will continue to widen until around 2090, at a separation of 6".

Some five degrees south-east of Gamma is **46 Vir (AGC 5)**, an 1876 discovery by Alvan Graham Clark, a member of the famous American family of telescope makers. At the time of discovery it was at 1.3" separation. Slowly closing since, it was measured at only 0.7" in 2005. An unequal pair like this, with 2.6 magnitudes difference between the components, is harder to separate than equal pairs. The Rayleigh criterion suggests about 20-cm aperture is needed here to place the secondary star between the primary's disk and the first diffraction ring. (The Rayleigh criterion = 13.8/D, where D is telescope aperture in cm). In 2013 I could see only glimpses of the companion at 336x with a 235-mm SCT, though in mediocre seeing.

Nearly one degree east-south-east from 46 Vir is **48 Vir (BU 929)**, discovered to be double by Sherburne Wesley Burnham in 1879, using the 47-cm Dearborn refractor. There has been a small increase in separation since, and Ernst Hartung fifty years ago noted that *"20cm shows the stars clearly apart"*. In 1998, with an 18-cm refractor at 330x, I saw the 7th-magnitude pale yellow pair as a figure-8. It's a very-long-period binary with the orbit not yet calculated.



Theta Virginis (STF 1724) is the brightest star found nearly on a line from Gamma Vir to Spica (Alpha Vir). It looks better than the numbers suggest. With 18cm at 100x it was an attractive combination of a bright white star with 9th-magnitude companion fairly close, and a wide 10th-magnitude star north-west. Haas with a 125mm refractor saw a colour contrast of yellow with bluish-turquoise for the closer stars. It's changed little since the first measure in 1831 by Wilhelm (FGW) Struve.

Next we'll use 3rd-magnitude Zeta Virginis as a guide star. Five degrees north-west of it is **STF 1734**, with **STF 1740** nearby to the east. STF 1734 is a close pair of 7th-magnitude stars, separated only 1.1"; the 18-cm refractor at 180x showed a nearly-equal close pair. STF 1740 is much wider, an easy small scope pair of 7th-magnitude deep yellow-orange stars, contrasting with two bright white stars in the field.

Located a third of a degree north of Zeta Vir, **STF 1757** is an 8th-magnitude orange star with a close 9th-magnitude companion; with my 235-mm SCT the stars were well seen at 124x with the wide 12.5-magnitude companion south-east. A nice object.

From Zeta Vir, 4.5 degrees north-east is **84 Vir (STF 1777)**, unequal and fairly close at 2.7". The orange magnitude 5.6 primary and 8th-magnitude companion showed neatly at only 100x with 18-cm, though I felt it was better at 180x. The best magnification for certain doubles varies; some pairs look best barely separated, others benefit from more magnification, so it's worth trying different eyepieces to see what gives the best effect.✦

***Ross Gould* has been a long-time observer from the suburban skies of Canberra. He can be reached at rgould1792@optusnet.com.**

Doubles of Virgo

Star Name	R. A. hh mm	Dec. ° ′	Magnitudes	Separation (arcseconds)	Position Angle(°)	Date of Measure	Spectrum
Gamma (STF 1670)	12 41.7	-01 27	3.48, 3.53	2.3" ephem	005° ephem	2015	F0V, F0V
46 Vir (AGC 5)	13 00.6	-03 22	6.2, 8.8	0.7"	180°	2005	K1IV
48 Vir (BU 929)	13 03.9	-03 40	7.1, 7.65	0.6"	198°	2007	F0V
Theta (STF 1724)	13 09.9	-05 32	AB 4.4, 9.4	6.4"	342°	2012	A0IV
"	"	"	AC 4.4, 10.4	71.1"	300°	2002	
STF 1734	13 20.7	+02 56	6.8, 7.3	1.1"	174°	2013	A3V
STF 1740	13 23.7	+02 42	7.1, 7.4	26.3"	074°	2011	G5V, G5V
STF 1757	13 34.3	-00 19	AB 7.8, 8.8	1.8"	135°	2011	K4III
"	"	"	AC 7.8, 12.5	56.3"	135°	2013	
84 Vir (STF 1777)	13 43.1	+03 32	5.6, 8.3	2.7"	226°	2011	K1III

Data from the *Washington Double Star Catalog*

Happy anniversary!

Celebrate a century of Melotte's star clusters.

One hundred years ago this month, *A Catalogue of Star Clusters shown on Franklin-Adams Chart Plates*, by Philibert Jacques Melotte, was received and read by the Royal Astronomical Society. Most of the star clusters were previously known, but this comprehensive catalogue was an effort to shed light on the distribution of both open and globular clusters. These were key factors in determining the structure of our galaxy and our position within it.

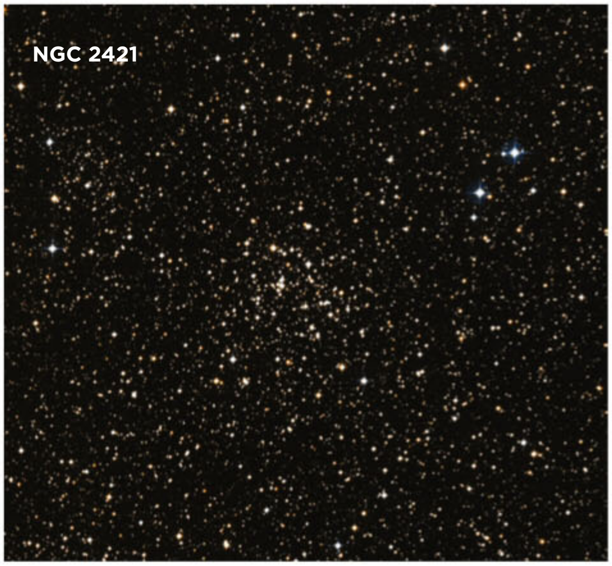
Let's take a look at some of the open clusters in Melotte's catalogue.

We'll begin with **NGC 2509** (Melotte 81) in Puppis. This is the nearest cluster we'll visit, only 3,000 light-years away from us. For an open cluster it's quite ancient, but just how ancient is still in question. Recent estimates of its age run from 1 billion to 8 billion years. Look for the cluster 1.9° west and a bit north of 4th-magnitude 16 Puppis.

NGC 2509 is a bright foggy patch flecked with stars through my 105-mm refractor at 17×. A 5th-magnitude star sits 41′ to the cluster's north-northwest, and a 9th-magnitude star guards its southeastern border. At 47× NGC 2509 is a dense knot of faint stars and bright mist, with a halo of dim stars that extends mostly southwest, through east, to northeast of the knot. I estimate dimensions of 8′ × 5′. About 25 stars are visible at 87×, some of the brightest making a rectangular box with the bright region packed into its northwestern side. The cluster looks almost completely resolved with my 25-cm scope at 187×, showing 40 faint to extremely faint stars, most crowded into the group's northern half.

Images of NGC 2509 show a faint edge-on galaxy 3.9′ south-southwest of the cluster's dense knot of stars. Its visual magnitude is probably somewhere in the vicinity of 15.5. Can you spot it?

Now picture an imaginary line from Rho (ρ) Puppis to 11 Puppis and extend it twice that distance to find our next cluster, **NGC 2421** (Melotte 67). My 105-mm refractor at 17×



POSS-II / CALTECH / PALOMAR OBSERVATORY

shows a fairly bright, round glow speckled with diamond-dust stars. At 47× the cluster resembles a star-spangled bowtie, tipped a bit away from us so that the near end is east-northeast. I count 25 stars in a group that spans 10′. A pair of 9th-magnitude stars sits 11′ northwest of the cluster and points toward it. About 35 stars emerge at a magnification of 87×. NGC 2421 has a rather triangular appearance through my 25-cm reflector at 88×, largely due to prominent triangles of stars at the cluster's north, south-southeast and south-southwest edges.

NGC 2489 (Melotte 79) hovers 13′ north of the 6th-magnitude red giant PX Puppis, which has low-amplitude variability of about 0.4 magnitude. NGC 2489 is a bright, granular haze through my 105-mm scope at 17×. At 87× it displays about 15 stars, surrounded by a gap and sitting in a bucket of stars open north-northwest. The bucket is about 9′ wide and the starry ball being carried inside is 5′ across. My 25-cm scope at 115× pries 35 faint to very faint stars out of the haze, forming a cluster that spans 8′.

Sliding 3.7° to the west-southwest from NGC 2489 takes us to **NGC 2439** (Melotte 74). It enfolds the yellow supergiant R Puppis, another

An edge-on galaxy floats about 4° to the south-southwest of the dense tangle of stars forming NGC 2509.

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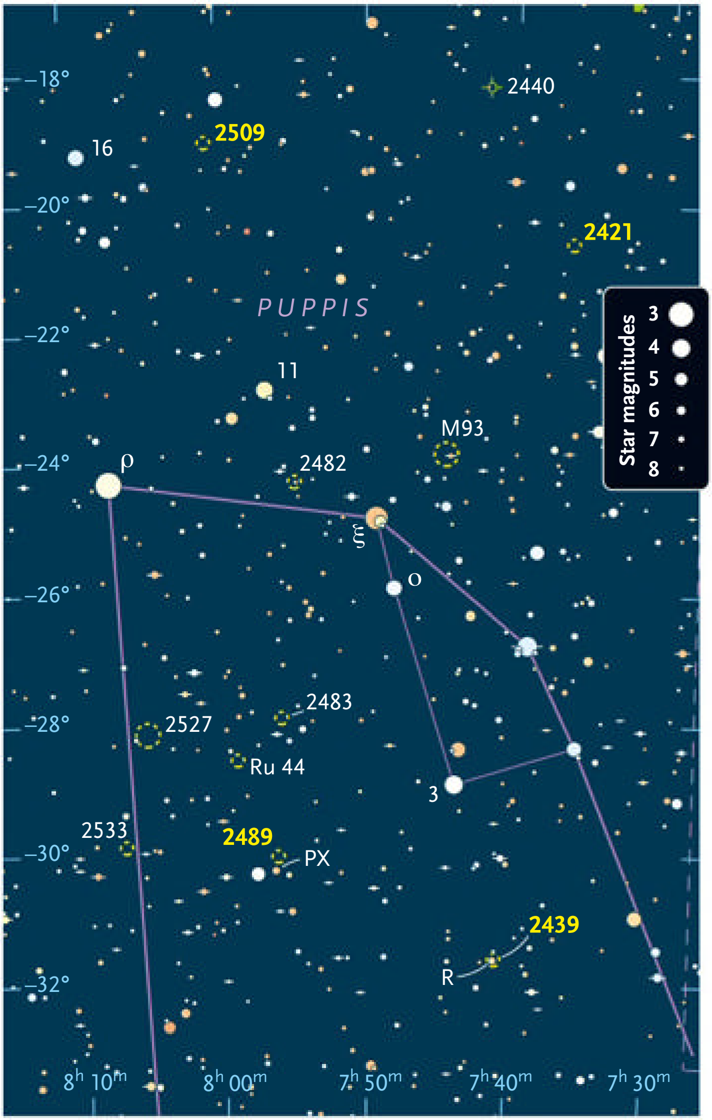
Melotte's Open Clusters

Object	Const	Mag(v)	Size/Sep.	Distance (l-y)	RA	Dec.
NGC 2509	Pup	9.3	12′	3,000	8h 00.8m	−19° 03′
NGC 2421	Pup	8.3	10′	7,100	7h 36.2m	−20° 37′
NGC 2489	Pup	7.9	8′	12,900	7h 56.3m	−30° 04′
NGC 2439	Pup	6.9	9′	12,600	7h 40.8m	−31° 42′
NGC 2627	Pyx	8.4	11′	6,600	8h 37.3m	−29° 57′
NGC 2658	Pyx	9.2	10′	6,600	8h 43.5m	−32° 39′

Angular sizes and separations are from recent catalogues. Visually, an object's size is often smaller than the catalogued value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.



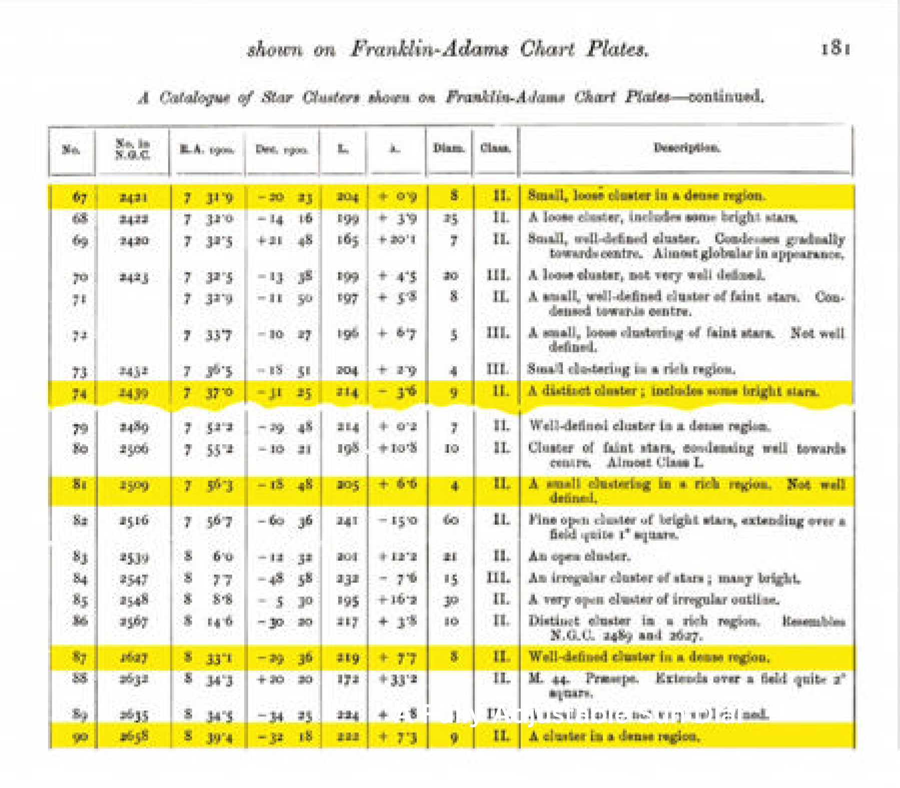
"NGC 2439 and NGC 2489 are the youngest star clusters in our tour, each with an age of only 18 million years."

low-amplitude variable star. Through my 105-mm refractor at 17×, R Puppis and three dimmer stars make a little kite in the northeastern part of a hazy glow that they share with four faint stars. At 47× two of the kite stars become double, and 14 additional stars appear. At 87× NGC 2439 is a pretty scattering of sparkly star motes, containing 32 members within a diameter of 8′.

NGC 2439 and NGC 2489 are the youngest star clusters in our tour, each with an age of only 18 million years. They have nearly the same galactic longitude, but NGC 2439 is a little closer to us and farther below the galactic plane than NGC 2489. This puts them roughly 900 light-years apart.

Just 350 light-years apart, NGC 2627 (Melotte 87) and NGC 2658 (Melotte 90) in Pyxis are the last stops on our anniversary tour.

NGC 2627 rests 40′ southwest of Zeta (ζ) Pyxidis. My 105-mm scope at 28× shows an east-west haze freckled with faint stars. A 9th-magnitude sun closely watches its east-northeastern edge. Amateur astronomer Joe Bergeron brought a detached fuzz spot 6′ south of NGC 2627's centre to my attention. This tiny island of mist is within the cluster's apparent boundaries as given in the *Milky Way Global Survey of Star Clusters* (Nina V. Kharchenko and colleagues, 2013), and one of its stars is considered a likely member. At 87× I see a hazy


shown on Franklin-Adams Chart Plates. 181

A Catalogue of Star Clusters shown on Franklin-Adams Chart Plates—continued.

No.	No. in N.G.C.	R.A. 1900.	Dec. 1900.	L.	λ.	Diam.	Class.	Description.
67	2421	7 31·9	−20 23	204	+ 0·9	8	II.	Small, loose cluster in a dense region.
68	2422	7 32·0	−14 16	199	+ 3·9	25	II.	A loose cluster, includes some bright stars.
69	2420	7 32·5	+21 48	165	+20·1	7	II.	Small, well-defined cluster. Condenses gradually towards centre. Almost globular in appearance.
70	2425	7 32·5	−13 38	199	+ 4·5	20	III.	A loose cluster, not very well defined.
71		7 32·9	−11 50	197	+ 5·8	8	II.	A small, well-defined cluster of faint stars. Condensed towards centre.
72		7 33·7	−10 27	196	+ 6·7	5	III.	A small, loose clustering of faint stars. Not well defined.
73	2432	7 36·5	−18 51	204	+ 2·9	4	III.	Small clustering in a rich region.
74	2439	7 37·0	−31 25	214	− 3·6	9	II.	A distinct cluster; includes some bright stars.
79	2489	7 52·2	−29 48	214	+ 0·2	7	II.	Well-defined cluster in a dense region.
80	2506	7 55·2	−10 21	198	+10·8	10	II.	Cluster of faint stars, condensing well towards centre. Almost Class I.
81	2509	7 56·3	−18 48	205	+ 6·6	4	II.	A small clustering in a rich region. Not well defined.
82	2516	7 56·7	−60 36	241	−15·0	60	II.	Fine open cluster of bright stars, extending over a field quite 1° square.
83	2539	8 6·0	−12 32	201	+12·2	21	II.	An open cluster.
84	2547	8 7·7	−48 58	232	− 7·6	15	III.	An irregular cluster of stars; many bright.
85	2548	8 8·8	− 5 30	195	+16·2	30	II.	A very open cluster of irregular outline.
86	2567	8 14·6	−30 20	217	+ 3·8	10	II.	Distinct cluster in a rich region. Resembles N.G.C. 2489 and 2627.
87	2627	8 33·1	−29 36	219	+ 7·7	8	II.	Well-defined cluster in a dense region.
88	2632	8 34·3	+20 20	172	+33·2		II.	M. 44. Praesepe. Extends over a field quite 2° square.
89	2635	8 34·5	−34 25	224	+ [illegible]8	[illegible]	[illegible]	[illegible] defined.
90	2658	8 39·4	−32 18	222	+ 7·3	9	II.	A cluster in a dense region.

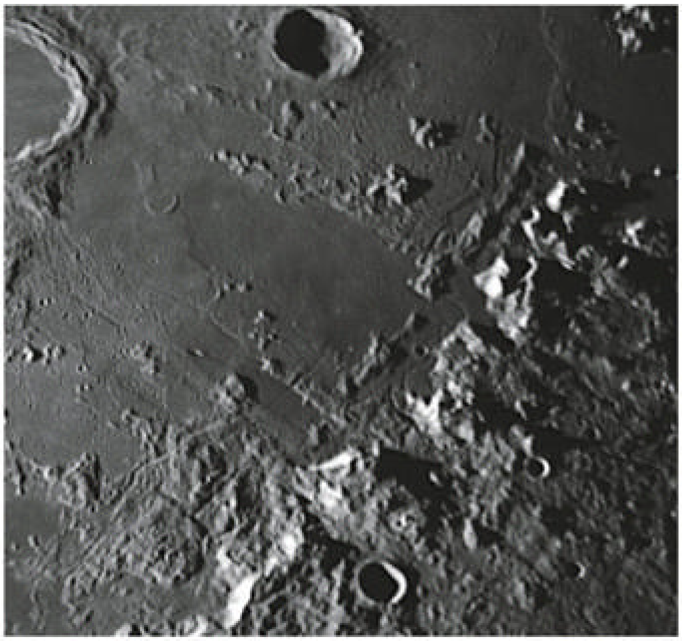
ROYAL ASTRONOMICAL SOCIETY / NASA ASTROPHYSICS DATA SYSTEM

glow adorned with 30 stars covering 11′ × 5½′, while the detached spot gives up only six stars in a triangular shape. At this same magnification, **NGC 2658**, which floats 32′ north of Alpha (α) Pyxidis, is an attractive sight boasting a liberal dose of very faint star specks over haze. Through my 25-cm scope at 187×, the centre of NGC 2658 is dominated by a broken ring of stars that outshines its surroundings and measures 1½′ × 1¼′. NGC 2658 sits in an open box outlined by brighter field stars, and the cluster's southwestern reaches ooze through the box's bottom.

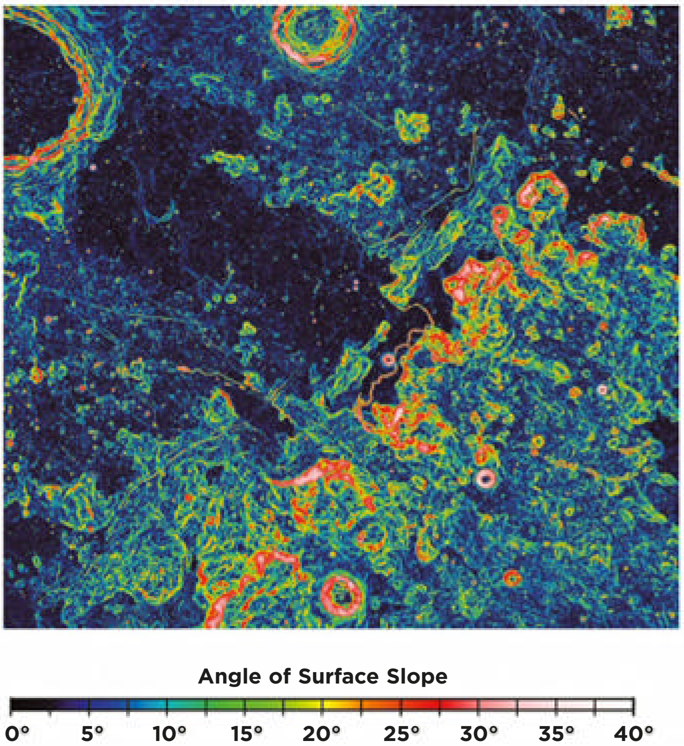
I'd like to thank astronomy author and astrogeologist Brent A. Archinal for providing the inspiration for this centennial celebration. Visit Melotte's catalogue online courtesy of **http://adsabs.harvard.edu/abs/1915MmRAS..60..175M.** ✦

Faulting the lunar crust

Subtle cracks and creases betray shifts in the lunar landscape.



DAVID STOREY



NASA/GSFC/LOLA SCIENCE TEAM

Top: The Apennine Front consists of towering peaks along the southeastern margin of Mare Imbrium. Sunlight gleams from stark fault scarps where slabs of rim dropped toward the basin floor. Above: A map from the LOLA altimeter on NASA's Lunar Reconnaissance Orbiter shows that slopes in this region can exceed 30°.

Fifty years of deep-space exploration have revealed this fundamental truth: impact cratering is far and away the most common geologic process on solid bodies in the Solar System. But faulting is high on the list too.

Our planet's crust is cut by thousands of faults, most resulting from the movement of the 100-kilometre-thick slabs of brittle rock that form Earth's crust. Most faults either slide these crustal plates horizontally past each other (California's San Andreas Fault comes to mind) or into each other, such as where the Pacific Ocean's Nazca Plate dives under the continent of South America.

By contrast, the Moon displays only a handful of obvious faults — and none were caused by plate movements. The Moon's most famous fractures are **Rupes Recta** (the classic Straight Wall) in southeastern **Mare Nubium** and **Rupes Cauchy** in northeastern **Mare Tranquillitatis**. In both cases one side of the mare's surface has dropped down a few hundred metres compared to the other.

But thousands of other lunar faults abound that we never think of as such. Impact craters larger than about 15 kilometres wide initially had walls too steep to be held in place by the strength of the lunar rocks. So huge slabs of the inner walls broke away and slid down as large blocks, creating giant concentric terraces. These movements occurred along fault planes that are often visible today as bright scarps just below crater rim crests. Look for them along the tops of the inner walls of **Copernicus, Theophilus, Tycho** and other large 'fresh' craters.

Telescopic observations made before the Space Age suggested that the slopes of these rim crests are inclined as much as 40° to 50°. Thanks to altimetric data from the Lunar Reconnaissance Orbiter (LRO), it's now possible to measure these slopes much more accurately. The steepest ones are generally 35° to 40°, implying that the narrow scarps along rim crests are even steeper. You can search for these by looking for ribbons of shadow hugging the rim crests of craters, after the Sun has locally risen high enough to illuminate more gently sloping topography.

The biggest faults on the Moon occur on the rims of the biggest craters. For example, the **Montes Apenninus** (Apennine Mountains) mark the edge of the 1,160-km-wide Imbrium Basin. Like a crater rim, this towering arc has a

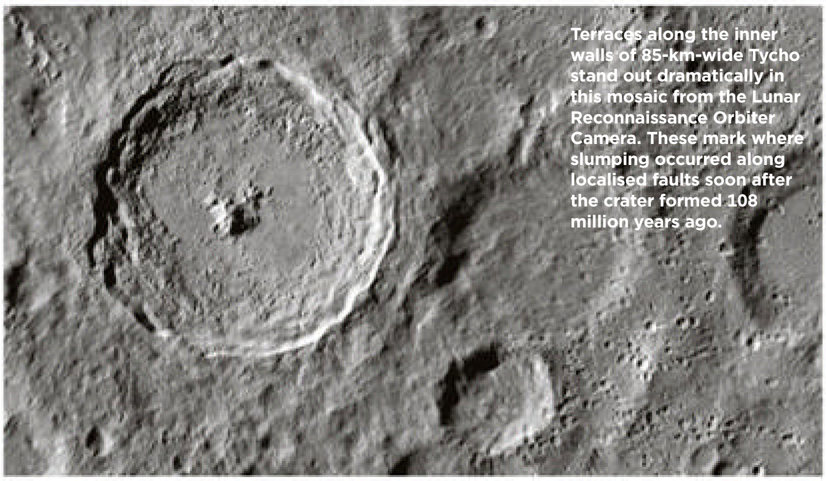
steep side facing the interior of the basin and a gentler slope gradually radiating outward. The 600-km-long Apennines rise more than 4 kilometres above the adjacent **Mare Imbrium**. This inner face, called the Apennine Front, is the top of a deep fault formed when the floor of the original Imbrium basin subsided. The fault probably slices 30 to 40 km down into the crust, curving inward with depth.

Another giant impact-generated fault scarp is visible as the inward face of the **Rupes Altai**, a mountain arc that rims the Nectaris basin and lies about 200 kilometres southwest of **Mare Nectaris** itself. Most other nearside basins are too old to have retained their rims' fault-faced scarps.

Stealth faulting

An unexpected class of faults are the low, sinuous ridges (*dorsa*) common in all maria. The most famous, informally named Serpentine Ridge, runs north-south for about 350 kilometres along the eastern edge of Mare Serenitatis.

For a long time these features were called 'wrinkle ridges,' which described how we thought they formed. As with some mountains on Earth, geologists thought wrinkle ridges resulted from horizontal compression that caused folding. On Earth, the compressional force is due to collisions between plates, and the mountain ranges thus created are a few hundred kilometres wide and 5 to 10 km high. But the Moon's wrinkle ridges are very different, typically only about 5 to 20 km wide and just 100 to 300 metres high. With slopes of only a few degrees, they can be easily observed



Terraces along the inner walls of 85-km-wide Tycho stand out dramatically in this mosaic from the Lunar Reconnaissance Orbiter Camera. These mark where slumping occurred along localised faults soon after the crater formed 108 million years ago.

NASA/GSFC/ARIZONA STATE UNIV.

only with low angles of illumination.

The mare ridges in Mare Serenitatis imply that these ridges formed due to a combination of folding and faulting. Imagine going back in time to watch the evolution of a just-formed impact basin, 500 km wide. In time, lava flows erupt from the heavily fractured floor and fill the basin to a depth of 4 or 5 km in the middle, thinning to nothing at the outer margins. All that added mass causes the basin's interior to sag, squeezing the now-solid pile of lava into a depression of smaller radius. This compression perhaps creates some folding concentric with the basin margin, but most of the volume reduction involves low-angle faults that thrust adjacent layers of lava over one another. Few of these faults actually breach the surface, but the ones at shallow depth trigger compressional folding in the topmost layers of lava — creating wrinkle ridges.

Curiously, LRO altimetry data show that the inward-facing sides of many mare ridges are 50 to 200 metres lower than their outer sides. This agrees with evidence from old Apollo ground-penetrating radar scans. Intriguingly, concentric mare ridges also occur at about the same relative distance from a basin's centre as do the inner rings of basins not inundated with lava (such as Orientale). And we see the same thing on a smaller scale where mare ridges mark the rims of buried impact craters, such as the one just south of **Lambert** in Mare Imbrium.

So mare ridges appear to be triggered by underlying topography of one kind or another. Keep a lookout for these and other faulty features when you're next eyeing the lunar landscape through your telescope. ✦

***Charles Wood* (lpod.wikispaces.com) is co-author of the new book *21st Century Atlas of the Moon*.**

Edge-on Galaxies

There's something special about these slender streaks of starlight and dust.

TED FORTE

Perhaps it's the symmetry, the simplicity or just the whimsical serendipity of finding an object so precisely aligned across our line of sight, but there's no denying that galaxies seen edge-on have a special allure. They're favourite targets for both visual observers and astrophotographers. They're also important targets for professional astronomers; their particular orientation enables measurement of stellar velocities along the length of the galaxy that can yield galactic rotation rate and reveal its mass. This makes edge-on galaxies important laboratories for, among other things, the study of dark matter.

The sky this time of the year contains many interesting examples of galaxies that, by happy accident, are inclined close to 90° from our vantage point. Some of these slender streaks of light will be crowned with bright bulges; others will be bisected by bands of dark obscuring dust. Many will, by virtue of the optical depth of the light path, appear brighter than they would if seen from more open angles. And in contrast, some will be devilishly hard to detect due to their ultra-thin profiles. If you're new to deep sky observing, I predict you'll find in this sampling a few objects that will amaze and inspire you, objects that you'll soon come to regard as favorites. Perhaps it will encourage you to seek out other examples of edge-on galaxies. There are many more in this month's sky than are mentioned here.

Our tour contains only objects not far from the celestial equator, and all of which should be detectable with telescopes of 25-cm of aperture from a semi-rural/suburban sky. In the table I've assigned a difficulty score to each galaxy. The score is based on a seven-point scale, where 1 is easy with a 25-cm scope and 7 would be undetectable. Your own results are likely to vary depending on your telescope, skies and experience level. I've also provided a recommended magnification that might optimise your chances of visual detection, similarly based on a 25-cm telescope. Consider this a reasonable starting point and adjust your magnification to suit your own tastes and conditions.

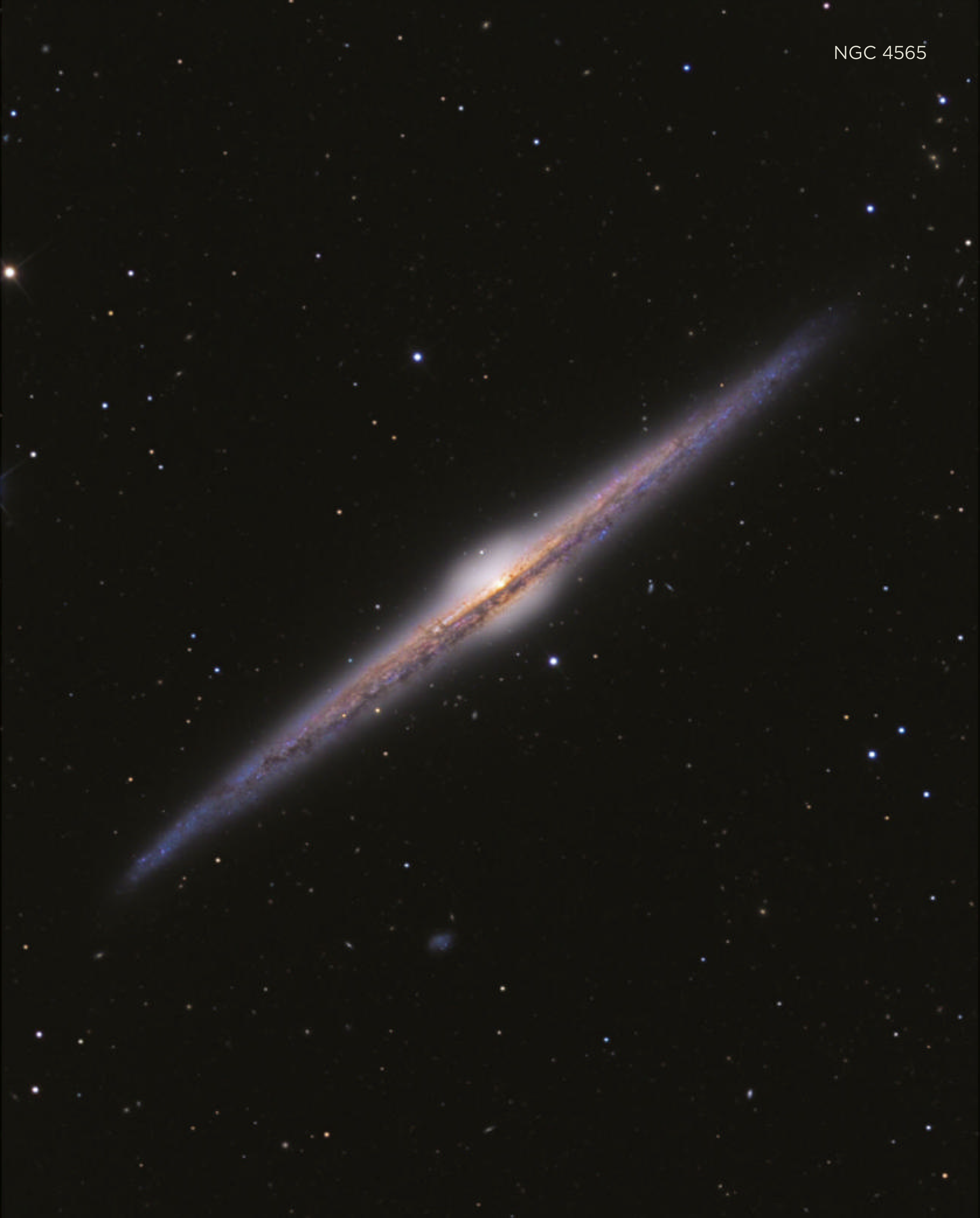
Position angle (PA) is key for viewing elongated galaxies. PA is measured along the major (long) axis of the galaxy from 0–180° starting from the north and rotating toward the east. A galaxy that angles exactly north-south would have a PA of 0°; an east-west galaxy would have a PA of 90°. Determining the PA of a galaxy can be tricky because first you must know the orientation of your field of view. Turning off your scope's motor drive will help you determine it; the direction of star drift indicates where west lies. If your telescope produces an inverted image, north will be counter-clockwise from west. If your telescope produces a mirror-reversed view, north will be clockwise from west. A telescope with an even number of reflections, like a typical Dobsonian, inverts the image. Those with an odd number of reflections, such as a Schmidt-Cassegrain or a refractor with a star diagonal, mirror-reverse what you see.

The tour begins

Hydra contains the only non-NGC/IC galaxy on our tour. To find **MCG –1-24-1**, look 4.5° west of Alpha (α) Hydrae, where your finder should easily pick up the nearly equal-magnitude star pair, 19 and 20 Hydrae. Our target is an easy hop from there, lying just 19.25′ east-southeast from 20 Hydrae. Detection of this slender beauty would be rather straightforward were it not for the 9th-magnitude star close alongside to the west. The star effectively hides the galaxy and might be the reason it doesn't appear in the NGC or IC catalogues.

Without foreknowledge of its presence, it would be a very lucky catch indeed, but by using the star to pinpoint the galaxy's exact location, you should be able to detect it. You'll be tempted to strain, but resist that urge; a relaxed eye is much better at detecting faint objects. You might find that the object will pop into view if you look away, relax your eye, and try

KEN CRAWFORD


NGC 4565

again. Angled just a little east of north, its position angle is 18°. Don't be discouraged if you find it difficult to make that estimate; it's a challenging thing to accomplish with an object that your eye can't fix with steady vision.

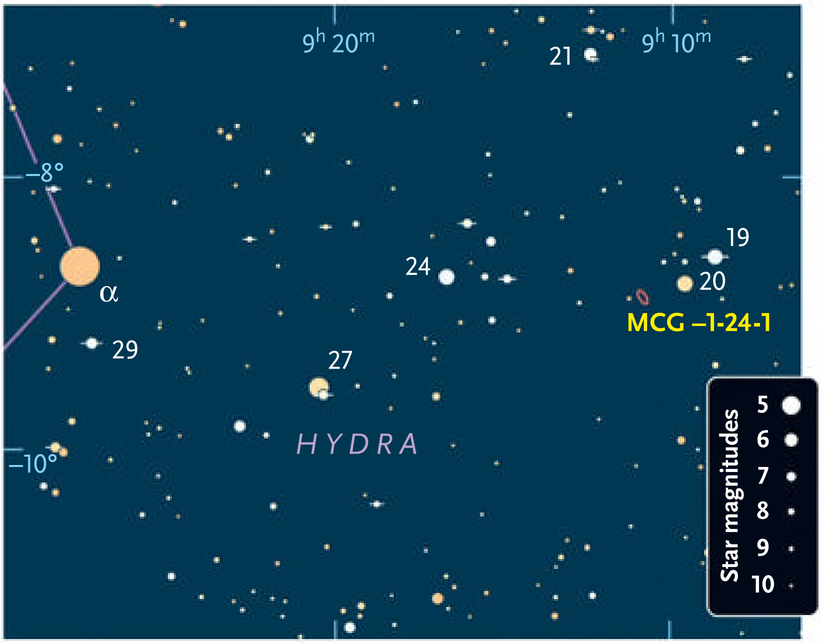
Our next streak-like galaxy lies about 54 million light-years away from Earth in the direction of Sextans. **NGC 3044** is moderately faint with a slightly brighter middle; it's angled northwest-southeast at position angle 112°. Through a large aperture telescope, the bright centre has a knotty appearance. Star hop from 7 Sextantis, which lies almost halfway between Alpha Leonis and Alpha Hydrae. The galaxy is just under a degree away to the southeast; a triangle of 9th-magnitude stars northeast of the galaxy points the way.

The head of Leo contains a compact group of four galaxies, designated Hickson 44, which resides almost halfway between Zeta (ζ) and Alpha Leonis. The edge-on galaxy **NGC 3190** is one of the brighter members of the group and lies almost 80 million light-years away from us. The galaxy has a bright core with a stellar nucleus. Owners of large scopes should try to detect a very subtle dust lane – it appears slightly skewed, which thought to be a result of the gravitational influence of the other galaxy group members.

Halfway between Psi (ψ) and Mu (μ) Ursae Majoris is our next target, **NGC 3432**, an edgeways streak in Leo Minor. This fine edge-on galaxy is probably interacting with a dim dwarf galaxy about 3′ to the west-southwest that isn't detectable with moderate-aperture scopes. NGC 3432 is also known as Arp 206, one of the 338 galaxies comprising Halton Arp's *Atlas of Peculiar Galaxies* (1966). It has a bright, dappled core and a disturbed-looking halo. There are three stars close by, a pair on the southwest tip and another star alongside to the southeast.

One out of three ain't bad

NGC 3628 in Leo has two popular nicknames. While many purists bemoan the assignment of these whimsical monikers, I think handles such as 'Sarah's Galaxy' adds interest



to the objects that earn them. 'Sarah' might refer to a 19th-century poet, but any definitive, authoritative source for the name seems lost. NASA's APOD images of NGC 3628 are labelled 'Hamburger Galaxy', and inevitably some observers will associate the galaxy with that title. Most of us, however, know NGC 3628 as the third and faintest member of the Leo Trio or Leo Triplet.

It's a fascinating object, well worth the extra effort it takes to detect its subtleties. The galaxy, 100,000 light-years across and 35 million light-years away, has a significant dust lane. Spectroscopic analysis of NGC 3628 reveals that the stars in its disk orbit opposite to the dust that comprises the galaxy's most prominent feature. This odd circumstance, it's thought, is evidence of a recent merger with another galaxy. NGC 3628 seems warped too, the flaring of its edges no doubt a result of gravitational interaction with its Messier galaxy neighbours.

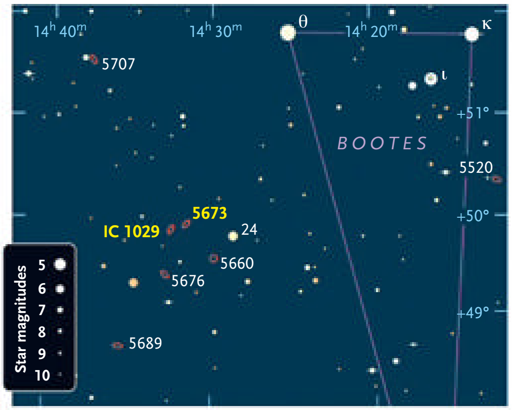
"Coma Berenices contains what I consider to be one of the most spectacular edge-on galaxies in the sky – NGC 4565, sometimes known as the Needle Galaxy."

Look for NGC 3628, along with its companions M65 and M66, about 2.5° southeast of Theta (θ) Leonis.

Coma Berenices contains what I consider to be one of the most spectacular edge-on galaxies in the sky. **NGC 4565** is sometimes known as the Needle Galaxy but might be better known as Berenice's Hairclip.
It's beautiful for its perfect symmetry and impressive due to its large size. A bright oval bulge is flanked by a well-balanced disk, its two gracefully tapering segments neatly bisected by a prominent dust lane. Choose a magnification that fills your field of view and you cannot help but be impressed. NGC 4565 lies just east of the large naked-eye-brightness star

KEN CRAWFORD

SHERRY AND STEVE BUSHEY / ADAM BLOCK / NOAO / AURA / NSF



Edge-on galaxies

Object	Const	Mag (v)	Size	RA	Dec	Score	Power
MCG-1-24-1	Hya	12	5.0′ × 0.9′	9^h 10.8^m	−08° 53′	4	120×
NGC 3044	Sex	11.9	4.8′ × 0.9′	9^h 53.7^m	+01° 35′	4	100×
NGC 3190	Leo	11.1	4.4′ × 1.5′	10^h 18.1^m	+21° 50′	3	100×
NGC 3432	LMi	11.4	6.8′ × 1.5′	10^h 52.5^m	+36° 37′	3	85×
NGC 3628	Leo	9.8	14.8′ × 3.0′	11^h 20.3^m	+13° 35′	3	40×
NGC 4565	Com	9.5	15.8′ × 2.1′	12^h 36.4^m	+25° 59′	3	65×
NGC 5746	Vir	10.8	7.4′ × 1.3′	14^h 44.9^m	+01° 57′	3	120×

The difficulty score ranges from 1 (easy) to 7 (undetectable) as described in the main text. Angular sizes and separations are from recent catalogues. Visually, an object's size is often smaller than the catalogued value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

cluster Melotte 111. Find it on the imaginary line connecting Alpha and Gamma (λ) Comae Berenices, approximately 3° from Gamma.

We'll end our tour with **NGC 5746** in Virgo, just 20′ west of the naked-eye star 109 Virginis and perhaps 95 million light-years from Earth. It's orientated nearly north-south and has a bright bulge and a prominent dust lane. The disk itself is diffuse, the opposing projections fading away without a sharp edge. Photographs show a very boxy core that might indicate a barred spiral, but that box-like centre isn't noticeable visually. An 8.5-magnitude field star sits about 5′ northwest of the galaxy.

It's so easy to get lost in the mechanics of detecting these faint patches of light that we might lose sight of the real significance of what it is we're capturing. I urge you not to let that happen. Galaxies may be viewed through the eyepiece, but they're appreciated through the imagination.

Part of the fun of observing has to be the flights of fancy that transport us to realms far beyond our galactic neighborhood and to worlds well beyond our reach. As the science of astronomy advances, so too does the reach of our mind's eye.

Understanding the true nature of these distant domains has provided us with an exponential expansion of our comprehension of our universe. For now at least, we can only explore that universe remotely, via journeys of thought taken through the telescope – but that's plenty good enough. ✦

Contributing Editor *Ted Forte* opens a monthly astronomy column for his local newspaper.

App-powered astronomy

Astronomers share their favourite celestial apps

The app world has exploded in recent years, and as a result, an abundance of astronomy apps for smart devices crowd the Apple and Android app stores. For an amateur astronomer seeking the best tools in the field, the bounty can be bewildering.

Rather than undertake an exhaustive review of all the apps available today — a review that might already be out of date tomorrow — we decided to take a 'word of mouth' approach. We asked around in our community, soliciting reviews from noted amateur and professional astronomers on the apps they use day in and especially day out. Instead of intensive descriptions detailing every tool's capabilities, we asked our contributors to focus on their favourite features that make each app stand apart. Read on for personal takes on apps that are fun, handy and often essential to practicing astronomy.

■ MONICA YOUNG

Scope Nights

Egg Moon Studio
Apple iOS

In a single glance, see your observing forecast over the next several hours or nights.

Amateur astronomers may not control the weather, but at least we can plan for it. Several astronomy-orientated weather apps are available, but Scope Nights has become my favourite. The beauty of the program is that you don't have to interpret weather data: the app gives each night a rating of good, fair or poor. Small but legible graphics show the night's general weather forecast, as well as details such as Moon phase and sunset and sunrise times. A colour bar shows any potential change in conditions over the course of the night.

The app uses GPS to obtain your current location, or you have the option of entering it manually, before it downloads global and local forecast data. You can also access a global light pollution app to find local dark-sky sites.

■ ROD MOLLISE, Contributing Editor

Starmap Pro

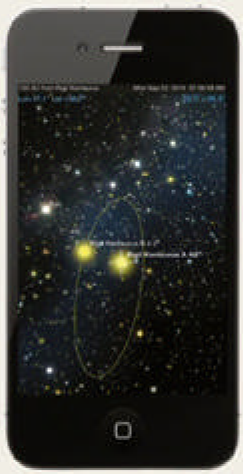
Frederic Descamps
Apple iOS

This planetarium program is customisable to your telescope's view.

Starmap Pro puts a capable planetarium program in the palm of my hand. It has all of the usual amenities, such as an extensive database (including 2.5 million stars) and an intuitive search function. Starmap Pro also tracks the real-time sky behind your device, helping you identify the celestial objects above you.

But its most powerful capability is an accurate depiction of my favourite eyepiece fields, and the ability to easily switch the eyepieces displayed. A twist of the wrist — flipping the mobile device over and back again — toggles the view between the eyepiece field and the sky map. This feature makes it one of my favourite apps.

■ TED FORTE, Contributing Editor



SkySafari 4

Simulation Curriculum Corporation
Apple iOS, Mac OS X, and Android

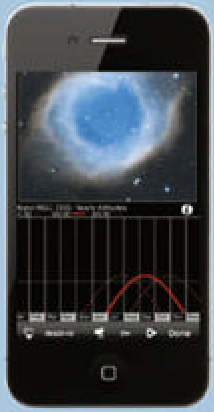
See what's in the sky tonight or take an adventure, like this trip into Alpha Centauri.

SkySafari is the big name in the world of astronomy apps. It wasn't the first planetarium program for smartphones and tablets, but it was the first to make a believer out of me. I didn't think you could squeeze a full-featured depiction of the night sky into a smartphone, and even if you could, I didn't believe it would be very usable.

This app changed my mind. To my surprise, SkySafari is not a compromise compared to desktop applications. All the usual elements are there: constellations, planets, the Moon, asteroids and comets, and tons of star clusters, galaxies and nebulae. The top of the line SkySafari Pro actually exceeds the object counts of some PC and Macintosh programs; it includes more than 27 million stars and 740,000 galaxies.

SkySafari can even do some things computer programs can't. Hold your device at arm's length and the app will use built-in sensors to provide a real-time view of the sky behind it. (This trick is now common to most planetarium apps.) Most impressive, though, is the legibility of SkySafari on a small screen. The graphics are even better on a larger display, becoming a thing of beauty.

■ ROD MOLLISE



Deep Sky Browser

Astro Devices
Apple iOS

Deep Sky Browser's catalogues and observing tools help you study deep sky objects such as the Ring Nebula.

Deep Sky Browser is the perfect companion to your printed star atlas or the myriad of planetarium applications. The heart of this app is a database of more than 51,000 deep-sky objects drawn from a wide variety of catalogues. A tap of the finger brings up the Abell Catalog of Planetary Nebulae, Arp and Hickson galaxies, the Messier and Caldwell catalogues, the IC, ESO, and NGC objects, and even a complete listing of all 2,500 Herschel objects.

But easy access to a large database isn't the app's only selling point. Users can select objects according to apparent magnitude and download their images from the Digitised Sky Survey. (You can combine different filters to show a colour image.) For each object, you'll find information such as its sky coordinates (RA, Dec), size, magnitude, surface brightness and rise and set times. Accompanying graphs show its visibility that day and over the span of a year.

This program was clearly designed with the serious observer in mind.

■ RICHARD JAKIEL,
Astrophotographer and deep sky and lunar observer

I've been a fanatical Moon observer for years, so I've used a wide variety of printed lunar atlases in my time. Fortunately, it didn't take long for an amazing lunar atlas to enter the app scene. Moon Map Pro has two sets of maps, a relief and topography map covering the nearside (based on Clementine spacecraft data), and Lunar Reconnaissance Orbiter (LRO) maps that cover the entire Moon. The relief map has about 1,200 named features, while the beautiful LRO images show more than 8,000. You can flip or rotate the charts to match the view through your telescope. The app includes a few helpful tools, too, such as a lunar libration calculator.

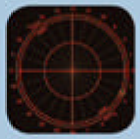
While I hope more features will be added in the future, Moon Map Pro continues to be one of my most-used apps.

■ ROD MOLLISE

Moon Map Pro offers two versions of detailed charts. The Lunar Reconnaisance Orbiter provides this view of Cleomedes crater.

Moon Map Pro

Kari Kulmala
Apple iOS



PolarAlign
George Varros
Apple iOS

This straightforward little tool will help you improve your telescope's polar alignment for deep-sky observing.

The app is simple, consisting of a 24-hour Right Ascension circle similar to the one found in polar alignment scopes, with two reference circles: 2010 and 2020. Using your current time and location, the app gives the offset of Sigma Octantis from the true south celestial pole (or the offset of Polaris from the north celestial pole). You can adjust the intensity of the app's red-light view and choose the orientation to match that of your scope's view (inverted, corrected, or right angle).

Using this modest app has improved my polar alignment and reduced the setup time for deep sky imaging.

■ RICHARD JAKIEL

Exoplanet
Hanno Rein
Apple iOS

Keep up with the breakneck speed of new discoveries in one of the most exciting areas of astronomical research. Exoplanet updates whenever a new planet is discovered, displaying its characteristics, such as mass, period, and size, its location and distance from Earth, the method of detection, and plenty more. Even better, the app links to all published scientific papers on the object in question, making the app a complete research tool.

■ ANDREW WEST, Assistant professor in the Department of Astronomy at Boston University
■ DR MARIO MOTTA, Past president of AAVSO and telescope builder

Exoplanet sends a notification with every discovery, then loads your device with all of the available information and observations.

Gas Giants
Software Bisque
Apple iOS

View our Solar System's four largest planets and their major moons through a simulated telescope of your choosing.

This is a neat little app that shows the main features and larger satellites of all the outer giant planets, useful for planetary imagers and casual observers alike. For starters, the app shows the current and future visibility of the Great Red Spot, the tilt of Saturn's rings, the dance of the Galilean satellites, and even the fainter major moons of Uranus and Neptune. Scroll along the time slider to animate any giant planet and its moons 24 hours into the near past or future. The best feature: pick a telescope-eyepiece combination and simulate the high-power view through your scope.

■ RICHARD JAKIEL

NightCap Pro
Chris Wood
Apple iOS

NightCap Pro turns your smartphone's camera into an astro-imager. Equipment editor Sean Walker used the app to take this photo of the Moon.

The iPhone has a nice built-in camera, so it's only natural that someone would eventually write an app to help take pictures in low-light conditions.

NightCap Pro allows users to take long exposures, capture night scenes, and even stack many frames to create star trail photos. The app includes some excellent features for those looking to toy around with astrophotography, such as focus lock, manual exposure, a self-timer and adjustable noise reduction.

This handy app has permitted me to take some impressive iPhone shots of sunspots, lunar craters, Saturn, and even an early-morning conjunction.

■ SEAN WALKER, Equipment Editor

JupiterMoons & SaturnMoons

Sky & Telescope
Apple iOS

The dancing retinue of Jupiter's and Saturn's moons enlivens our fascination with the Solar System's gas giants. Amateurs have long relied on graphs and tables for moon positions, but *Sky & Telescope* now has two convenient apps that perform the same function.

JupiterMoons focuses on the four Galilean moons, Io, Europa, Ganymede, and Callisto, while SaturnMoons features nine satellites: Titan, Rhea, Iapetus, Dione, Tethys, Enceladus, Mimas, Hyperion and Phoebe (the latter a challenge even for large telescopes). The apps also accurately display the position of Jupiter's Great Red Spot and the tilt of Saturn's rings.

Each app opens with the moons in their current configuration, and easy-to-use controls let you plan ahead or explore the past in jumps of a year, month, day, hour, 10 minutes, minute or second. You can even animate the display — the 10-minute interval works well if you want to watch the moons orbit their planet.

Essential to the JupiterMoons app is its table of satellite events, which lists moon and shadow transits, occultations and eclipses. Click a table entry to see the view of Jupiter and its moons during the given event.

Other controls include night-vision mode, which turns the screen red, and buttons that flip/rotate the image to match the view through your telescope. 'Learn more' buttons lead to extensive entries exploring the characteristics (and oddities) of each planet and its moons.

■ ALAN FRENCH,
Telescope maker and longtime observer

EclipseDroid

Wolfgang Strickling
Android

Thousands of skywatchers are willing to venture anywhere on Earth to witness a total solar eclipse. Paramount for any such trip is knowing exactly when and how long totality will last from a specific location, and how the Moon's traverse across the solar disk will look during the event. That's the predictive niche filled by EclipseDroid, a handy app developed by astrophotographer and self-professed umbraphile Wolfgang Strickling.

The app welcomes you with a sped-up animation of the next solar eclipse as seen from wherever your device happens to be. You can also change your location: select from an interactive map or a database of world cities or enter the latitude and longitude manually. Then touch 'Eclipse details' to see the screen fill with specific times and sky (alt-az) coordinates for the event's key contact events, along with a plethora of other details.

Users of the free app have access to solar eclipse info from the recent past through 2015. The full version offers circumstances for events from 3000 BC to AD 3000. (The full version can be free too, if you download the app directly from Strickling's website.)

EclipseDroid also supports scripting that can, for example, step your USB-connected DSLR camera through a preprogrammed sequence of images while announcing a countdown in English, German or Italian. But this app has its limits, excluding features such as complex image sequences, that are available on desktop applications.

■ J. KELLY BEATTY,
Senior Contributing Editor

Astronomy Picture of the Day

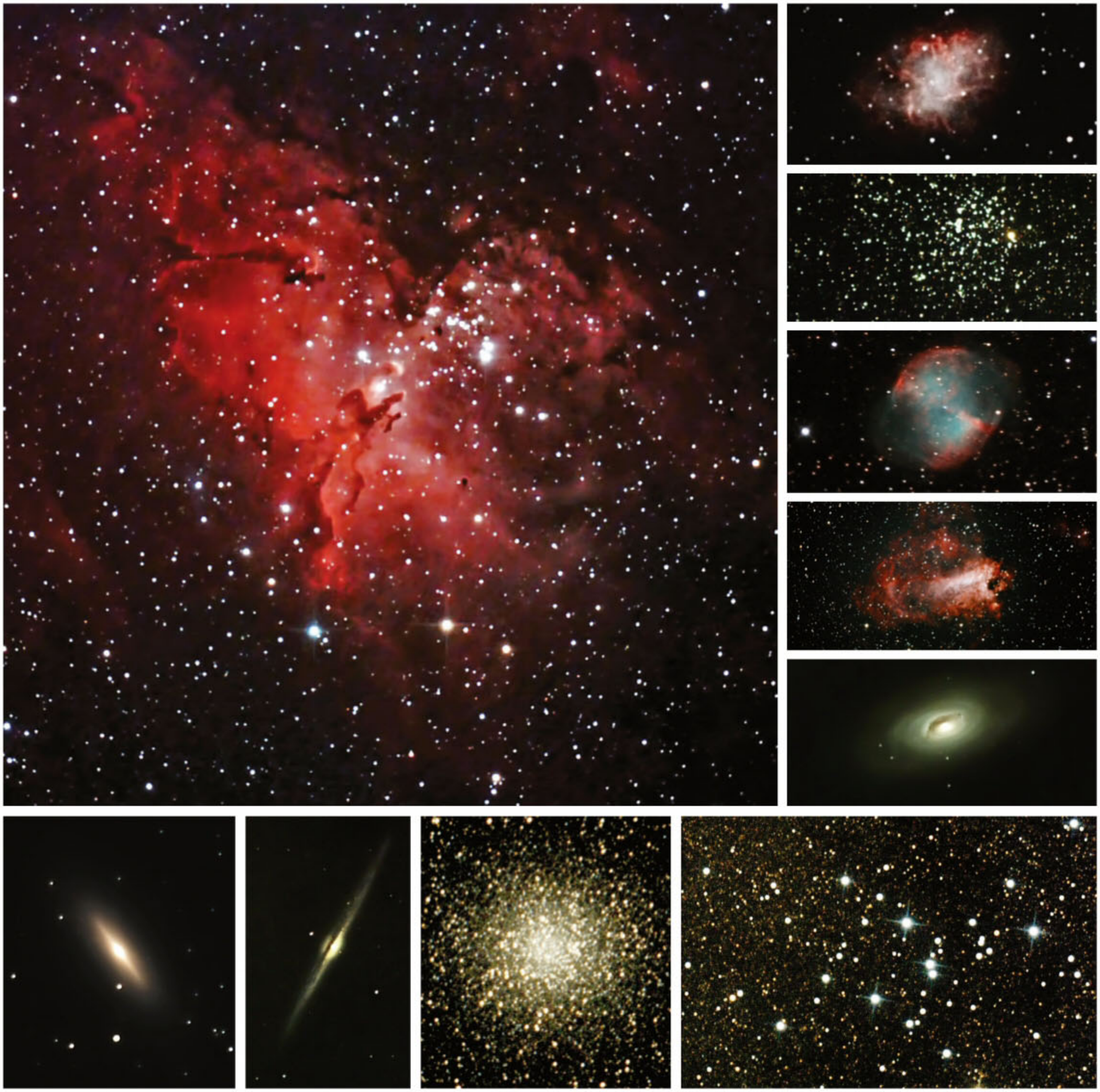
Concentric Sky
Apple iOS and Android

APOD shows a stunning new astrophoto every day, such as this Hubble Space Telescope image of the Cat's Eye Nebula.

This simple app is a worthwhile addition to any astronomer's smartphone. Updated daily, the app displays the famous Astronomy Picture of the Day, which often draws from current events in the astronomy world. Professional astronomers Robert Nemiroff (Michigan Technological University) and Jerry Bonnell (NASA Goddard) write most of the accompanying descriptions. The images are always spectacular and the explanations informative and written at an accessible level. ✦

■ ANDREW WEST

Backyard DSLR imaging



Get the most out of your imaging from any location with these helpful tips.

While digital SLR cameras continue to change the landscape of astrophotography, many amateurs are unaware of their ability to capture good astrophotos from under suburban light-polluted skies. DSLR images clockwise from upper left corner: M16, M1, M52, M27, M17, M64, M7, M22, NGC 4565 and NGC 3115. UNLESS OTHERWISE NOTED, ALL IMAGES ARE COURTESY OF THE AUTHOR.

BY RICHARD JAKIEL

Like many imagers, I live under the pervasive glow of urban light pollution, where the closest dark-sky site requires a substantial drive. But rather than limit my imaging to those rare nights I can make the trip, I've learned to mitigate many of the problems of my location to take respectable images with my DSLR and a variety of telescopes of many targets once thought out of my reach. Whether you're starting out in astrophotography or have been shooting for some time, the tips shared here can help you take impressive photos of galaxies, nebulae and star clusters with a DSLR and telescope from the comfort of your own neighbourhood.

Settings for astronomy

Plenty has been written about the strengths and versatility of DSLR cameras. The latest models incorporate high-sensitivity, low-noise CMOS detectors that rival the performance of many CCDs used in dedicated astronomical cameras. But unlike CCD cameras, DSLRs are equally at home taking everyday photos as well as long exposures of faint galaxies.

To get the most out of your DSLR photos taken under any sky, some changes to the basic camera settings will greatly increase the quality of your images. The first setting to choose is the manual mode in your camera. This enables you to control important features including exposure length and colour balance. For deep-sky imaging, you'll most often be using the 'bulb' exposure, which lets you to keep the shutter open longer than 30 seconds. This is necessary to record all but the brightest objects visible to the naked eye.

Next, be sure to set your camera to save images in 'RAW' format. This is a proprietary format (saved with the extension NEF in Nikon cameras, while Canons use CR2) in 16-bit format that preserves all the light you recorded. Other file formats (particularly JPEG) compress your images to save space and introduce unsightly artifacts. You'll need to use the software that came with your camera or another image-processing program to convert your RAW files into other file formats, but the additional image quality is worth it.

Now examine your camera's ISO setting. This is similar to the gain setting on video cameras; the higher the value you use, the more sensitive your camera will be and the shorter the exposure you'll need. The latest DSLR models boast extremely high ISO settings — in some it can be in excess of 50,000! But there is a cost. While it's tempting to image at these extremely high values, this approach adds noise and also reduces the dynamic range of your image. Star colours are washed out, and the image appears noisy. I recommend using an ISO setting of 400 to 800 as a good compromise to preserve colourful star clusters and planetary nebulae, while selecting higher values when capturing galaxies and other nebulae.

S&T: SEAN WALKER

Besides your camera, you'll need at least two other accessories to take photos through your telescope. A T-ring adapter replaces the lens on your camera and connects it to the focuser on your telescope, while a digital intervalometer (left) lets you to program and shoot multiple exposures.

Calibration – half the work

A large part of taking good astro-photos with a DSLR is making sure you use good calibration frames. These are called dark, bias and flat-field images, and they're used to reduce unwanted thermal and optical effects in your images.

Due to the electronic nature of CMOS (and CCD) sensors, the longer you expose the sensor to light, the warmer the detector gets. This creates thermal artifacts that build up in your photo, which appear like static or noise in exposures that are longer

A lot of light pollution comes from local sources, with verandah lights, streetlights and headlights all adding up. The author sets up his equipment so that all nearby lighting sources are blocked from shining directly into his telescope.

Bright Galaxies for Urban Imagers

Object	Constellation	Mag(v)	RA	Dec.
M31	And	3.4	0^h 42.7^m	+41° 16′
NGC 253	Scl	7.6	0^h 47.6^m	–25° 17′
NGC 891	And	9.9	2^h 22.6^m	+42° 21′
M77	Cet	8.8	2^h 42.7^m	-0° 01′
M65	Leo	8.5	11^h 18.9^m	+13° 05′
M66	Leo	9.0	11^h 20.2^m	+12° 59′
M100	Com	9.4	12^h 22.9^m	+15° 49′
M84	Vir	9.3	12^h 25.1^m	+12° 53′
M86	Vir	9.2	12^h 26.2^m	+12° 57′
M64	Com	8.5	12^h 56.7^m	+21° 41′

By shielding his equipment from direct lighting and shooting only when the object was in the darkest part of his backyard sky, the author managed to capture this deep, colourful image of M33 using a 20-cm f/3.9 Newtonian astrograph and twelve 10-minute exposures.

than a few seconds. Dark frames are photos taken of the same duration and temperature as the images of your target, but with the camera or telescope's aperture covered to record only the thermal signal in your image. These frames are then subtracted from your pictures, making them appear less noisy. Most DSLRs today have very little dark current, so imagers often skip this calibration frame.

Bias frames record the fixed-pattern noise inherent in all digital detectors and are taken at the very fastest shutter speed you have. These are likewise subtracted from your photos, as they help to reduce the uneven banding seen when you ‘stretch’ an image to reveal faint details during post-processing.

The last calibration frame is the flat-field image. This is a snapshot of an evenly illuminated surface that records the vignetting of your lens and dust motes on the detector that plague virtually every optical system but are more pronounced when shooting under light-polluted skies. When properly applied, flat-field calibration can greatly reduce if not eliminate these optical effects.

Flat-field images can be recorded in various ways using the darkening sky during twilight or with an evenly illuminated screen. No matter how you choose to take your ‘flats,’ they need to be recorded in the exact same optical configuration used for imaging during an entire evening. It’s important to have your telescope focused before taking flats so that you accurately record the location of any dust motes, and you should not rotate the camera for the rest of the night.

Flat-field images should also be exposed to have the highest-level register at about ⅓ to ½ of the histogram display. This is a graph feature in your camera that shows brightness levels and is plotted from left (black, or no signal) to right. Consult your camera’s manual to see how to display the brightness histogram on your particular model.

Once you’ve recorded all these calibration frames, consider picking up an additional computer program that can apply them to your photos. Although you can capture your images in your DSLR with only the addition of a cable release and the camera’s Bulb setting, you’ll need a dedicated astronomical processing software program to properly calibrate and adjust the images.

Managing your sky

With all the preparation done, you’re ready to start imaging. Spend a little time determining where the best part of your sky is. Light pollution not only washes out the sky, it also introduces unusual background hues and brightness gradients that can be tough to deal with. To top it off, light pollution is never uniform across the sky; instead it’s more concentrated in the form of light domes rising up from the horizon. But a little bit of strategy will usually mitigate these problems. Set up your scope in a location that best blocks local sources of light and shoot in the direction away from the most intense light domes.

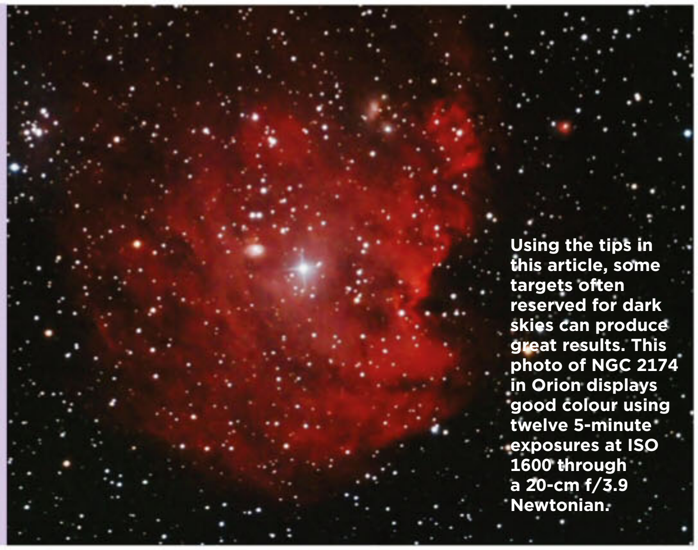
When imaging under urban skies, try to plan your evenings to shoot multiple targets that best utilise both your local conditions and your time throughout a night. Take advantage of your chosen targets’ paths across the sky by planning to image them only when they are away from light domes, or when they are simply highest. This lets you avoid following a single subject as it goes from a dark spot in your sky and into a brighter area later in the evening. While this approach might spread your acquisition of a particular target over multiple nights, you’ll get better images overall.

Even when avoiding light domes, there will still be some light pollution in your images that lightens the entire frame. This brightness effectively decreases the signal-to-noise ratio (SNR) in your photos, limiting how long you can expose your individual pictures before reaching the sky limit where there is no benefit to exposing longer. When shooting with a DSLR, this occurs when the detector becomes saturated or the sky background gets very bright. You can find the sky limit by taking a series of progressively longer exposures at your chosen ISO and then examining the photo histograms. If the plot of the histogram begins at about the middle of the graph, you should try a shorter exposure.

The best way to work around the sky limit at your location is to take many exposures of the same object and

Bright Nebulae for Urban Imagers

Object	Constellation	Mag(v)	RA	Dec.
M1	Tau	8.4	$5^h\ 34.5^m$	+22° 1′
M42 (and M43)	Ori	3.0	$5^h\ 35.4^m$	–5° 27′
NGC 2174	Ori	—	$6^h\ 9.7^m$	+20° 30′
M8	Sgr	5.8	18h 3.8^m	–24° 23′
M16	Ser	6.0	$18^h\ 18.8^m$	–13° 47′
M17	Sgr	6.9	$18^h\ 20.8^m$	–16° 11′
M57	Lyr	8.8	$18^h\ 53.6^m$	+33° 2′
M27	Vul	7.3	$19^h\ 59.6^m$	+22° 43′
NGC 6888	Cyg	—	$20^h\ 12^m$	+38° 21′
NGC 7662	And	8.3	$23^h\ 25.9^m$	+42° 33′



Using the tips in this article, some targets often reserved for dark skies can produce great results. This photo of NGC 2174 in Orion displays good colour using twelve 5-minute exposures at ISO 1600 through a 20-cm f/3.9 Newtonian.

combine (or stack) them into a single image later. This increases the SNR in your photo, allowing you to record fainter details in your images while greatly reducing the noise compared to single exposures.

The actual gain in signal when stacking multiple images is equal to the square root of the number of frames stacked. For example, if nine 5-minute exposures are stacked, the relative gain in SNR is only $\sqrt{9}$, or 3. So the resulting stack is effectively what you'd record in a single 15-minute exposure. When imaging from urban locations, stacking will be the technique that adds the most to the quality of your images.

Battling gradients

As mentioned earlier, you'll always be recording gradients in your images when shooting from suburban locations. To really maximise your efforts, consider purchasing a light-pollution suppression (LPS) filter. These filters use interference technology to block most wavelengths associated with common forms of urban light pollution while passing most of the photons from deep-sky objects, increasing the contrast in your images by up to a factor of three.

Still, despite these best efforts, gradients will show up in your images and can present a real processing challenge. Fortunately, most astronomical image-processing programs include tools to effectively deal with these problems. Processing suites such as MaxIm DL (www.cyanogen.com), PixInsight (http://pixinsight.com) and others include tools to correct gradients.

While there is no true substitute for dark skies, you don't always need to be under pristine skies to take great deep-sky astrophotos or improve your imaging technique. With a little understanding of your DSLR camera and the effects of light pollution, a great deal can still be done under less-than-ideal conditions that let you end up with some impressive results. ✦

Richard Jakiel **is an experienced observer and astrophotographer who observes and images under suburban skies.**

Tele Vue's BIG Paracorr Type-2

During my years of testing astronomy equipment, I've worked with some of the world's finest telescopes designed for astrophotography. (And feel free to substitute the word 'expensive' for 'finest' in that sentence, if you'd like.) I've used telescopes made by Officina Stellare, PlaneWave, Takahashi and Tele Vue, as well as top-of-the-line equipment from Celestron, Meade, Star-Watcher, Stellarvue and others. The astrophotos with this review, however, weren't made with any of them. Rather, they were taken with a 30-cm Meade LightBridge Dobsonian that I bought second-hand for $500. All I did was add Tele Vue's new BIG Paracorr Type-2 coma corrector to the scope and, voilà, I had imaging performance that was on par with the best astrographs I've tested.

The devil, they say, is in the details, and there definitely are some between "add Tele Vue's BIG Paracorr" and "voilà." The most significant involve fitting the telescope with a 7.5-cm focuser that would accept the BIG Paracorr and attaching

Tele Vue BIG Paracorr Type-2

Tele Vue's BIG Paracorr was key to transforming the author's 30-cm f/5 Newtonian reflector into a first-class optical system used for the astrophotography with this review. The image above of the grand spiral galaxy M33 was assembled from 40-minute exposures through red, green and blue filters with a CCD camera fitted with a KAF-16803 chip. All colour astrophotographs with this review were processed by the author's colleague Sean Walker.

ALL PHOTOS BY THE AUTHOR

WHAT WE LIKE:

- Extraordinary coma correction for fast Newtonian reflectors
- Excellent coverage of large-format CCD chips
- The potential to make top-notch astrophotography more affordable

WHAT WE DON'T LIKE:

- It is currently of interest mainly to do-it-yourselfers

the tube assembly to an equatorial mount suited for astrophotography. I also upgraded the scope's secondary mirror to a larger one that provided better field illumination for imaging. Except for this mirror, I made all the parts for these modifications, but they could have easily been done with parts available commercially. I'll come back to this scope later, but for now let's look at the real reason I could turn a onetime Dobsonian reflector into a world-class astrograph — the BIG Paracorr.

Tight star images and fine resolution are possible with the BIG Paracorr as apparent in this image of the globular cluster M15 assembled from sets of 12 1-minute exposures made through red, green and blue filters.

Why a coma corrector

At the close of the 19th century, photographic plates were replacing the eye as astronomy's workhorse detector. Telescopes were essentially becoming giant camera lenses, and the never-ending quest for bigger apertures shifted from refractors to reflectors having parabolic primary mirrors — a trend that culminated with the completion of the 5.1-metre (200-inch) Hale Telescope in the late 1940s. Parabolic mirrors are also at the heart of the Newtonian reflectors familiar to all amateur astronomers today, even if we hear the name Dobsonian (derived from the style of mounting) more often than Newtonian.

Newtonians with parabolic primaries have many advantages, but they suffer from coma. This inherent optical aberration distorts stars into seagull-like flares that grow larger the farther they are from the centre of the telescope's field of view. Visual observers tolerate coma by moving objects to the centre of the eyepiece field where images appear sharp. But coma is a curse for astrophotographers striving to capture pinpoint stars across big fields. The problem becomes worse as the imaging detector grows larger, and it grows worse for mirrors having shorter focal ratios (lower f/numbers), which are desirable for astrophotography. This holds true regardless of the mirror's aperture. For example, any f/3.3 parabolic mirror (the focal ratio of the primary in the Hale Telescope) produces acceptable star images across a field less than 15 millimetres in diameter. Fortunately, wider fields are possible if a multi-element, coma-correcting lens is introduced near the telescope's focal plane.

Yerkes Observatory astronomer Frank E. Ross was America's foremost astronomical lens designer in the early 20th century. He developed some of the first coma correctors, including ones for the Hale Telescope that gave well-corrected fields about 7.5-cm in diameter. Later correctors designed by Charles G. Wynne provided even larger fields.

Commercial coma correctors for amateur astronomers have come and gone over the years, and a handful exist today that are designed for telescopes with 5-cm (2-inch) focusers. Some are made for visual observers, some for astrophotographers, and some for both. I've tested several, including one a few years ago that prompted me to build a 20cm f/3.3 Newtonian for astrophotography with DSLR cameras having APS-size sensors. The results were acceptable enough for me to start work on a 30-cm f/4 Newtonian, but I stopped after upgrading my astronomical CCD camera and DSLRs to models with sensors that were too big for the field coverage of the coma corrector.

Until Tele Vue introduced its BIG Paracorr Type-2, the only current source of coma correctors capable of adequately covering large-format detectors such as the popular KAF-16803 CCD from ON Semiconductor (formerly Truesense Imaging, which was formerly Kodak) was Astrosysteme Austria (ASA). Like the BIG Paracorr, even ASA's smallest corrector, which is based on a Wynne design, needs a 7.5-cm focuser.

The BIG Paracorr Type-2

Building on the success of the 5-cm Paracorr Type-2, Tele Vue's Paul Dellechiaie designed the 7.5-cm BIG Paracorr Type-2 for use with CCDs as large as the KAF-16803 and parabolic mirrors as fast as f/3. It was introduced in April last year, and a few months later I borrowed one of the first production models for some testing.

The BIG Paracorr has an extremely generous 80 millimetres of back focus (a third more than ASA's correctors), allowing ample room for attaching all the astronomical CCD cameras and filter wheels that I'm familiar with, as well as all DSLRs. In many cases

Designed mainly for astrophotographers, the BIG Paracorr has optional spacers and adapters to couple it with many DSLR and astronomical CCD cameras. But there is also an optional adjustable top that allows the corrector to be used visually with a wide range of Tele Vue eyepieces.

The author's first images with the BIG Paracorr were with a 40-cm f/3.2 parabolic mirror mounted in a plywood tube that he made years earlier to test other coma correctors. The first-light image here is an uncalibrated 10-second exposure of the star field around Polaris showing pinpoint stars across the frame of the large-format KAF-16803 CCD. Some vignetting is apparent in the corners of the frame, but the shadowing at left is due to the Paracorr extending into the setup's light path, an unavoidable artifact of the tube's layout.

there is even enough back focus with the BIG Paracorr to squeeze in a low-profile off-axis guider.

The BIG Paracorr moves the telescope's original focal plane outward a bit more than 72 millimetres (an engineering drawing showing all the relevant spacings is available on Tele Vue's website). As with the coma correctors that Ross designed for the Hale Telescope, the BIG Paracorr slightly increases a telescope's effective focal length, with a corresponding increase in f/ratio. For the BIG Paracorr this magnification increase is 1.15×, meaning that an f/3 mirror effectively becomes an f/3.45 imaging system.

Were it not for my experiments with coma correctors in the past, the BIG Paracorr would have been a challenging product to test given the rarity of fast Newtonians with 7.5-cm focusers, not to mention ones set up for long-exposure imaging. But I had a 40-cm f/3.2 parabolic mirror configured as a Newtonian in a plywood 'tube,' albeit one that wasn't intended for an equatorial mount. Nevertheless, I modified its focuser to accommodate the 7.5-cm Paracorr and simply propped up the tube in my driveway so I could shoot the field around Polaris where the sky's slow diurnal movement allowed minute-long exposures with minimal star trailing.

My first exposures with a CCD camera having a KAF-16803 CCD were remarkable. Despite the crudeness of the setup, the BIG Paracorr yielded perfectly round, virtually pinpoint stars across the frame. Vignetting was minimal in all but the very corners, and there was no discernible change in focus for exposures made through clear, red, green and blue filters.

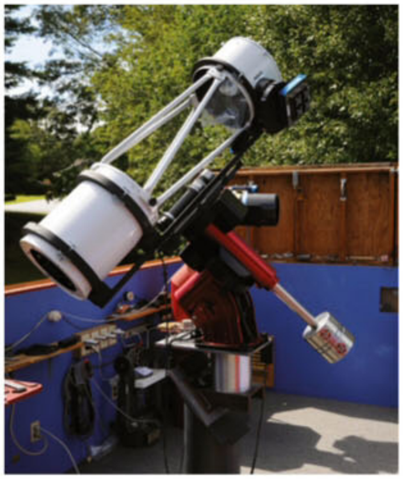
Plans immediately began swirling in my head for turning the 40-cm into a telescope for astrophotography, but a much faster way to test the Paracorr for long-exposure imaging was to modify my old 30-cm LightBridge Dobsonian. While I did this as a temporary test setup, in hindsight it wouldn't be a crazy idea to consider a LightBridge fitted with the BIG Paracorr as a permanent astrograph from the outset. This isn't a story about telescope making, so I'll skip the details, but it's worth noting that modifications costing me less than $270 ($215 of which was for the 10-cm secondary mirror), produced a telescope that made the images accompanying this review. It's certainly something I think about when I compare my results with those I've obtained while testing commercial astrographs priced well north of $10,000.

Notes from the field

As mentioned above, I don't know of any commercially available big Newtonians that have fast f/ratios and are made for long-exposure astrophotography. So there's no way for me to address how the BIG Paracorr will perform with specific telescopes people are going to use it with (which is another way of saying that, for now, deep-sky astrophotography with the BIG Paracorr is mainly in the hands of do-it-yourselfers). That said, my field notes will still be of interest to people considering the BIG Paracorr for imaging.

The filtered exposures used to assemble the colour images with this story were all done with a fixed focus — I did not refocus the telescope when switching between filters. I simply set my initial focus shooting

Despite the BIG Paracorr's lenses being relatively near the telescope's focal plane, exposures are remarkably free of ghost images and haloes even when very bright stars are in the field. This 30-minute shot of the Pleiades was through a blue filter.



Long-exposure tests were done with the BIG Paracorr fitted to a 30-cm Meade LightBridge reflector that is described in the text. The scope's pedigree is apparent during a 'photo op' the day it was attached to a Paramount ME II. In practice, however, the scope was wrapped in a light shroud and fitted with a tube extension that prevented stray light from reaching the Paracorr's front lens located just inside the wall of the telescope's tube. The working setup towered over the author who is nearly 6 foot 4 inches (193 cm) tall.

through the green filter. I could, however, obtain ever-so-slightly tighter star images for the red and blue filters by tweaking the focus. In a perfect world I might have done that, but in the practical world I found it unnecessary.

Because my test setups were only meant to be temporary, I cut a few corners when modifying the tube assemblies for the 40- and 30-cm mirrors. As such my cameras ended up never being perfectly square to the scopes' optical axes. And while I could achieve good optical collimating, it too was never perfect in either setup. Regardless, I performed various tests that proved to me the BIG Paracorr can form nice, tight, round star images across the full frame of a KAF-16803 CCD. Close examination of images showed that the first sign of degraded focus was a tiny elongation of star images (which mimicked poor guiding) followed by the expected bloating of stars as the focus became worse.

There is little question that I'm excited by the potential of the BIG Paracorr. It clearly raises the imaging performance of humble Newtonian reflectors with fast primary mirrors to a level that can compete with today's elite astrographs having exotic optical designs. And it also opens up a world of possibilities for 'old-school' astrophotographers like me who got started in this hobby because we could build (and afford) the telescopes we used. ✦

Dennis di Cicco has been writing about telescope equipment for more than 40 years.

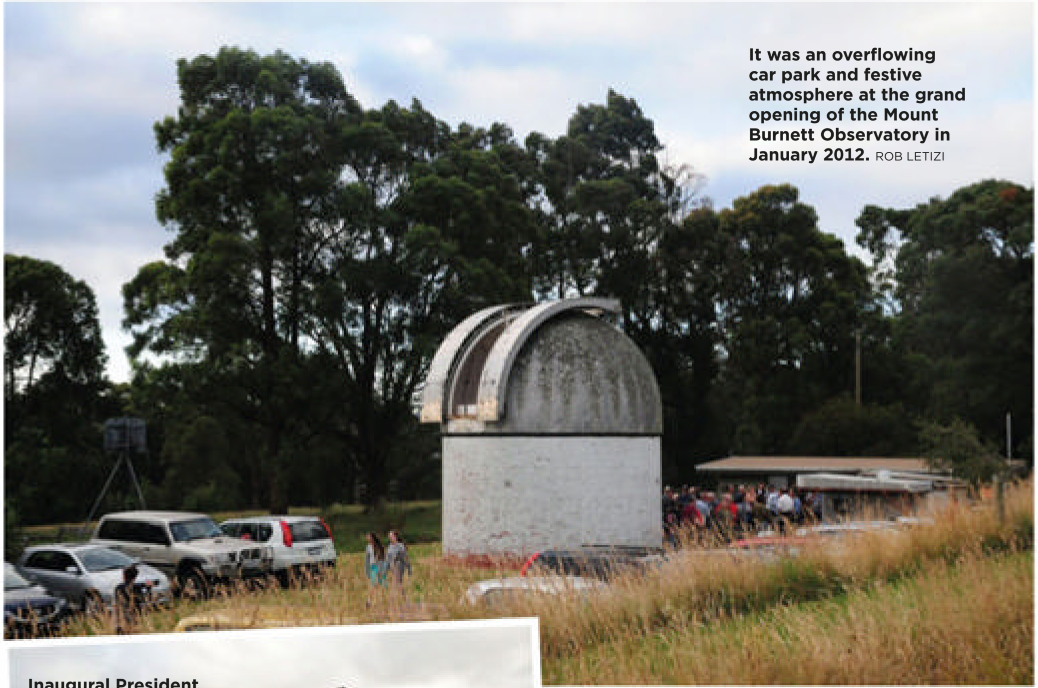
Some long-exposure tests with the 30cm reflector and BIG Paracorr were with a CCD camera having a KAF-8300 chip. Because this CCD is smaller than the KAF-16803, vignetting is insignificant, and this view of the sinuous nebula VDB 142 in Cepheus was processed without a flat-field calibration.

Full-resolution images (left and right) cut from the corners of an uncalibrated 1-minute exposure of the Pleiades (centre) made with a KAF-16803 CCD show the quality of the star images as well as the darkening caused by vignetting at the very corners of the chip. From corner to corner the KAF-16803 covers an imaging circle spanning 52 millimetres.

Old observatory's second chance

PERRY VLAHOS

Once abandoned, Mount Burnett Observatory is home to a thriving new community of astronomers in Victoria's Dandenong Ranges.



It was an overflowing car park and festive atmosphere at the grand opening of the Mount Burnett Observatory in January 2012. ROB LETIZI

Inaugural President of MBO, Perry Vlahos, welcoming attendees to the Grand Opening celebrations. ROB LETIZI

Looking for Venus at twilight wit on Observatory's third anniversary open day in January 2015. HEIKE REICH

Is it possible for a new astronomical association to begin from scratch with no members and within three years become the fastest growing group in Australia, and the second largest astronomical society in Victoria? The answer is a resounding 'yes' if you're Mount Burnett Observatory Inc.

But first, let's hop into the Tardis for a quick trip to Australia in 1972 - the land of safari suits, big flares, big hair, big platform soles… and big ideas. One of the latter was for Monash University to establish its own research-grade observatory in the nearby Dandenong Ranges. In the early 1970s, the funding available for such projects — when compared with today's impoverished policies — was as plentiful as Kingswood station wagons. Monash Observatory was thus established at Mount Burnett, some 45 minutes drive east of the university's Clayton campus.

A 40-cm reflecting telescope was installed, and soon observer's quarters were added. A newer telescope with a superlative quality 45-cm mirror replaced the old one in 1985. Finally, a second, 25-cm telescope was installed in a roll-off roof shed… lovingly referred to as the 'Chook House'.

Through the years, Mount Burnett was a reliable workhorse for Monash, boasting more clear nights per year than Melbourne city. Many astrophysics students undertook work at the observatory towards the completion of their honours and doctoral theses.

Now let's fast-forward to 2011, at which point the observatory had been left unused since 2004. The original university staff had retired, hardly anyone knew how to use the instruments, and students now travelled to Siding Spring Observatory in New South Wales to use the newer and much larger telescopes there. So the observatory had been left to gather dust and rust.

The university offered the buildings and telescopes to the Astronomical Society of Victoria (ASV). The society, rightly or wrongly, decided not to take up the offer and the observatory was left in danger of being dismantled. In a last gasp effort to save it, four senior ASV members (including the author) and a local resident, formed a new astronomical association — the Mount

The refurbished dome with its newly painted exterior, and the 'Chook House' roll-off roof observatory at right. CHRIS SAMUEL

Burnett Observatory Inc. — and put up their own money to sign a new lease agreement for the site.

Our hope was to save and restore the observatory for the use of members, the local community and educational institutions. With hard work and a focus on community, perhaps doing more outreach than any other astronomical association in Australia, we have succeeded beyond our wildest dreams. Locals from the Dandenong Ranges in particular have given us incredible support.

MBO's current telescopic arsenal sees the venerable 45-cm telescope figured by hot-shot mirror-maker Bill James still under the main dome, the 25-cm still in the Chook House, plus a fleet of 20-cm and 25-cm Dobsonians for the members to use, as well as an Octagonal 5-inch refractor donated to the observatory. Discussions are under way to augment these with a couple of large modern instruments.

We are still actively seeking members and more aid to refurbish the whole facility. If you'd like to become a member, make a donation, or offer any assistance whatsoever, we would love to hear from you, so that we may continue to share the sky for all.

For more information, visit the MBO website at mtburnettobservatory.org ✦

10 & 5 Years Ago

May 2005

NASA in crisis

"Lock the doors." With these three quietly spoken words, NASA Flight Director Leroy Cain confirmed the unthinkable — the United States had lost another space shuttle. That was in 2003. Now, in 2005, NASA was about to fly again, with shuttle Discovery ready on the launch pad. Seventeen years earlier, Discovery had borne US astronauts back into space 32 months after the loss of Challenger and her seven crewmembers in January 1986. Fortunately, her new flight went without a hitch, and the shuttles were back in business.

May/June 2010

Solar System out of balance?

Will the planets ever go haywire? We take for granted the clockwork stability of planetary orbits. Nobody worries that Mercury will run rampant in the inner Solar System. There's no serious concern that Mars will smash into Earth. After all, the planets have been stably circling the Sun for the last 4.54 billion years. If anything could go wrong, you'd think it already would have. But chaos theory suggests that perhaps we should not be so certain.

Astro Calendar

VASTROC
April 17-19
Biennial Victorian astronomy conference, hosted in 2015 by the Bendigo Astronomical Society
vastroc.net

RASNZ Conference
May 8-10
Annual meeting of New Zealand's astronomers
rasnz.org.nz/Conference/

Trans-Tasman Symposium on Occultations
May 11
Australasian get-together for occultation observers, this year to be held in Lake Tekapo, NZ
occultations.org.nz

South Pacific Star Party
May 14-17
Annual star party hosted by the Astronomical Society of NSW
asnsw.com/spsp

CWAS Astrofest
July 18-19
Annual conference held in Parkes (home of 'the Dish'), including the David Malin Awards
cwas.org.au/Astrofest/

Queensland Astrofest
August 7-16
Annual star party
qldastrofest.org.au

National Science Week
August 15-23
Lots of public astronomy activities held around Australia
scienceweek.net

StarFest 2015
October 2-4
Three days of activities during the Festival of the Stars
starfest.org.au

Siding Spring Open Day 2015
October 3
Australia's largest optical observatory throws open its doors to the public
starfest.org.au

WHAT'S GOING ON?
Do you have an event or activity coming up? Email us at editor@skyandtelescope.com.au.

Astrophotos from our readers

▲ **CARINA NEBULA**

Chris Marklew

For this shot of part of the famous Carina Nebula, Chris used a PlaneWave CDK 12.5 scope at f/8 on a Paramount ME, plus a SBIG STT-8300M camera with filter wheel (Astrodon Ha and Oiii) and AO-8T adaptive optics. Exposures were Ha (180minutes), Oiii (180), being 30-minute sub-exposures at bin 1x1.

◀ COMETARY GLOBULE CG-4

Colin Eldridge

Cometary globules have nothing to do with comets; they just look a bit like them. For this shot of CG-4 Puppis, Colin used a Plane Wave CDK-700 telescope, FLI Proline-16803 camera and Astrodon Gen-2 RGB filters. Total exposure time was 7.3 hours in 10-minute sub-frames.

▲LAGOON NEBULA

Mike O'Day

Mike image of the Lagoon, also known as Messier 8, used a Skywatcher Quattro 25-cm scope on a Skywatcher AZ Eq6 GT mount, Starshoot AutoGuider, Nikon D300 camera, PHD2 guiding software, Baader MPCC Mark 3 Coma Corrector and UHC-S 'nebula' filter. Exposures were 23 x 240-second sub-images.

▲ RHO OPHIUCHI CLOUD

Joe Perulero

Joe's picture of this spectacular region of Scorpius required three hours exposure. He used a 'modded' Canon 500D with Samyang 85mm lens at f/2.8 and Astronomik CLS CCD filter on an Ioptron Skytracker.

▶ CELESTIAL POLE

Paul Brown

For this startrail of the deep southern skies, Paul stacked 283, 3200iso, 15-second sub-images (with a 5 second gap between them), taken with tripod-mounted Canon 500D at f/3.5. Stacking was done with the freeware Startrails program.

◀ TRIFID NEBULA

Rod Walsh

The Trifid is always a favourite target for observers and imagers. Rod used a Celestron SCT 11-inch Edge HD with Celestron .7x Focal Reducer, mounted on a Celestron Cgem DX. The camera was a Canon 60Da; exposures were 50 x 300-second sub-images.

HOW TO SUBMIT YOUR IMAGES

Images should be sent electronically. Please first send a low-res JPG version to contributions@skyandtelescope.com.au, and we'll get back to you with information on how to send your hi-res versions if selected. Please provide full details of all images, eg. date and time taken; telescope and/or lens used; mount; imaging equipment type and model; film (if used); filter (if used); exposure or integration time; and any software processing employed. Readers who have a contributed image published in *Australian Sky & Telescope* will receive a 3-issue subscription to the magazine.

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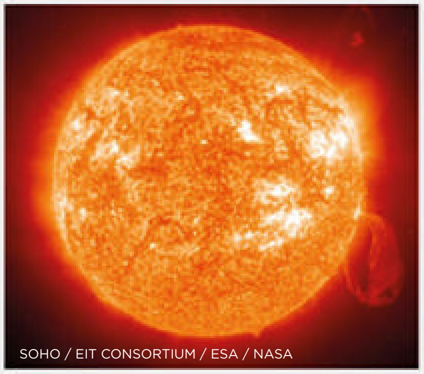
ESO

Our first look at Pluto

NASA's New Horizons mission will reach Pluto in mid-July, giving us our first close-up look at what used to be called the ninth planet.

Jules Verne revisited

What did educated people think about space travel and the Moon in 1870? Much that was both wrong and right, judging from a science fiction classic.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Secrets of solargraphy

Try a fun astrophotography project that doesn't need a telescope.

Abell 2065

You'll need patience and tenacity to observe this Corona Borealis galaxy cluster..

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Farewell to a friend

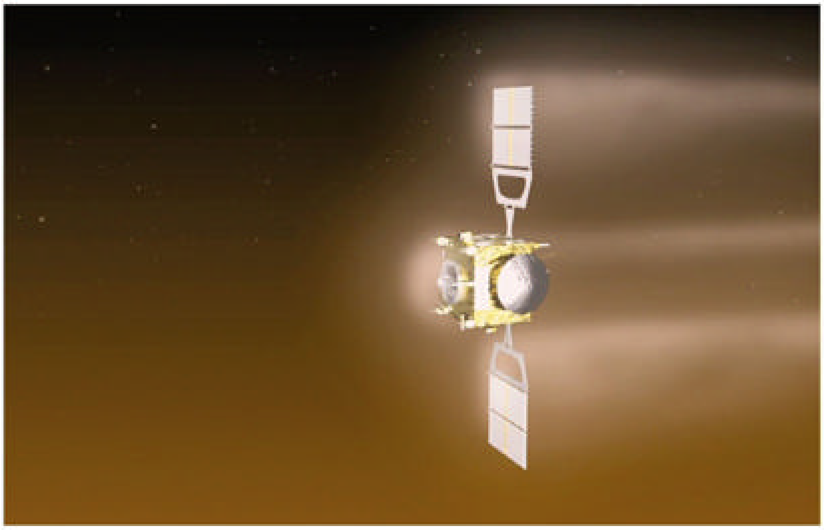
The tremendously successful Venus Express mission has come to an end.

It's time to say goodbye, and thanks, to a friend who has served us well. For me the friendship began in 2006 with a letter from the European Space Agency (ESA) informing me that I had been selected as a member of the Science Team for the Venus Express mission. This was a dream come true. I had been fascinated with 'Earth's twin' at least since the 5th grade when I read Isaac Asimov's novel *Lucky Starr and the Oceans of Venus*, which described epic battles and exotic aquatic creatures.

I soon learned that this fantasy had been obsolete since 1961, when Mariner 2 — the first successful mission to another planet — had proved Venus far too hot to host oceans or surface life. The harsh reality dashed Venusian water-world fantasies but raised delicious new questions: What happened to take these twin worlds, Earth and Venus, down such different paths? What could we learn from this about the life stories of other Earth-like planets? Further spacecraft results hinted that Venus was likely once cooler and wetter. We began to see it as a place where planetary climate had gone off the rails, into the hot zone.

The plucky European Venus Express spacecraft arrived in April 2006 and orbited for eight great years, providing our first continuous, detailed observations of the cloud-shrouded planet. It revealed a vibrant world of constantly shifting cloud patterns, immense tornado-like vortices dancing chaotically around the poles, intense bursts of lightning, and seemingly active volcanism.

By the beginnig of 2015, we knew we were living on borrowed time. Venus Express had long since exceeded its originally expected mission lifetime, and all last year it had been running low on the fuel to power its thrusters. The last phase of the mission was focused on dynamic and variable phenomena, both on the surface, where we used the infrared spectrometer to scan for volcanic activity, and in the upper atmosphere, where we monitored the changing abundance of



sulfur dioxide above the clouds.

Doing science to the end, we tried some risky manoeuvres we would not have dared attempt earlier in the mission. In June and July of last year we performed a series of 'aerobraking' experiments, lowering the orbit to an altitude of 130 kilometers, well into the thin uppermost atmosphere. The resulting changes in spacecraft motion allowed us to compute the density of the air, which we found was surprisingly variable and more strongly affected by time of day than expected. New data like these help us build better climate models for Venus — and for Earth.

We had hopes that the mission might last longer, but the spacecraft's orbit had been decaying. We planned a series of 10 daily rocket burns for the last week of November to raise the orbit. These could have kept the spacecraft safe until February, when another series of burns could have kept it going until June. The suspense came from the fact that we didn't really know how much fuel was left. It was like running on fumes with your car's fuel tank warning light on, except we knew when we ran out there would be no roadside assistance.

On November 28, during one of these rocket burns, the spacecraft stopped communicating normally and suddenly seemed unable to maintain proper orientation with its antenna focused on Earth. Venus Express was still alive, still sending out telemetry, but we couldn't establish a good communication link, and it soon became clear that its fuel had run out, and there was nothing more to be done. On December 16, ESA announced that the mission was over. Sad but proud emails darted among the science and engineering teams, with congratulations on an amazing mission and reminders of the years of data analysis still to be done.

It really is like saying goodbye to a friend after so many years of making plans, sending instructions, receiving images and data, losing and regaining contact, worrying over problems, crossing our fingers, and rejoicing when everything is okay. After years of this sort of thing, you become attached.

Sometime around the end of January the spacecraft was expected to plunge into the atmosphere, falling in pieces, corroding and melting, toward the searing planetary surface.

Goodbye, Venus Express. Please tell Venus that we'll be back. ✦

***David Grinspoon* is an astrobiologist and author. Follow him on Twitter on @DrFunkySpoon.**